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A STUDY OF GAS CALORIMETERS

by

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A Thesis Submitted for the Degree of

CHEMICAL ENGINEER

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A STUDY OF GAS CALORIMETERS

During the last ten years the consumption of gas for heating purposes, whether in stoves, ranges, or in incandescent lamps, has increased enormously, and it is generally conceded tnat from 80 to 90% of all gas consumed is used for its heating value. Before gas was used so generally for heating, and while being employed mainly for illumination with an open flame burner, the candle power of the gas was the principal standard by which the product was judged. Up to the present time in the United States, the candle power standard has been adopted more generally than the heating value standard. In Germany the importance of calorimetry has been more generally recognized, and many cities for some time have required tests of both calorific values and candle power. The English regulations have not always been so consistent as the German in requiring heating value tests, but in recent years England has also adopted a calorific standard to accompany the candle power.

The Public Utilities Law of the State of Wisconsin in 1907 required the Railroad Commission to regulate the quality of service of the various public utilities and this called attention to the gas service in this state, and the need of a suitable standard by which to judge the quality

of gas. A conference of gas and electric managers, engineers, and investors was called in Madison in March, 1908. At this conference the concensus of opinion seemed to be that the greatest bulk of gas sold was used for heating and incandescent lighting, and therefore a heating value standard would appear to be the most equitable method of testing the value of gas. Subsequent to this conference the Railroad Commission adopted the calorific standard for gas.(1)

Recognizing the desirability of a heating value standard it became most important for the gas company as well as for the consumer that an efficient calorimeter be employed. Several manufacturing companies were selling calorimeters, but no authoritative information appeared to be available by which to judge the relative merits of the various types of calorimeters. The Engineering Department of the Railroad Commission desired an investigation of the matter and the writer assumed the laboratory work upon which conclusions were to be based. About this time a "Committee on Calorimetry" was appointed by the American Gas Institute to investigate the same question,-- this committee consisting of Mr. R. B. Brown, Engineer of the Milwaukee Gas Light Company, Mr. J. B. Klumpp, Inspecting Engineer of the

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(1) Bulletin #27 Railroad Commission.

United Gas Improvement Company, and Prof. C. F. Burgess, of the Chemical Engineering Department of the University of Wisconsin, and also connected with the Engineering Staff of the Railroad Commission.

On account of the identity of interests of the Railroad Commission and the American Gas Institute in conducting the investigation, a co-operation was effected and the greatest part of the laboratory work was carried on in the Chemical Engineering Laboratories of the University of Wisconsin. With the investigation the writer was directly interested and worked upon it with Mr. Ross C. Cornish, Manager of St. Joseph, Mo. Gas Company, Mr. D. A. Powell, Superintendent of Gas, of the Madison Gas and Electric Co., together with the members of the Committee named above.

The results of the tests on the relative and absolute efficiencies carried on up to September, 1908, were given in the report of the Committee on Calorimetry to the American Gas Institute and published in Vol. III, 1908, of the Transactions. Since then the investigations have been continued in the Chemical Engineering Laboratories by the writer.

CHAPTER I.

Types of Calorimeters.

The types of calorimeters used for determining the heating values of gas are varied, but they come generally under two heads-- constant volume, and constant pressure types.

The calorimeter which gives the heating value of a gas at constant volume is usually of the bomb type, because the energy of combustion exerts a high pressure on the container if the volume is kept constant. This type of calorimeter is not suited for determining the heating value of gas in ordinary technical operation. Because of the bomb construction, the volume is small in comparison to weight of material, and thus gives a small change in temperature; it is exceedingly difficult to fill the bomb with gas and know its exact volume. It requires a highly skilled operator to obtain satisfactory results, because of the difficulties in manipulation. The apparatus is too expensive to be available in most gas works or municipalities.

The constant pressure type of gas calorimeter is in almost universal use in this country and abroad. The heat of combustion of the gas at atmospheric pressure is transmitted through thin metal walls to a known volume of water whose rise in temperature is observed. Since the heat of combustion of the gas is transferred to water, the principle of counter-currents is used-- that is, the products of

combustion and the water absorbing the heat are kept moving in opposite directions. The water as it enters the calorimeter meets the products of combustion as they leave, and there are thus two channels separated by a metal partition, and the water leaves the calorimeter just above the combustion chamber of the gas. This type of apparatus requires the use of a thermometer at both inlet and outlet of the water,to determine the rise in temperature.

This type of calorimeter possesses many advantages over the constant volume type. The volume of gas for a test is limited only by the size of suitable measuring devices for the water. The gas is measured in a separate device whose accuracy is easily determined and kept constant. By using a comparatively large volume of gas for a test, any small inaccuracy in the gas meter produces only a small percentage error in the final result. The operator of this type of calorimeter does not need to be so highly skilled as is necessary in the constant volume type. The expense in procuring this device is not excessive for a first class instrument. This instrument with careful use will last a long time.

Besides the above mentioned types of calorimeters there are several other types which in principle are really constant pressure calorimeters, but which seek to eliminate

the use of water and make the device as automatic as possible. Among such devices are: (a) The Fery (1) which records the difference in temperature between the air supply for combustion and the flame temperature by means of a sensitive thermo-couple. The instrument is calibrated with a gas of known composition and heating value-- such as hydrogen. (b) The Casaubon (2) device measures the amount of air necessary for the complete combustion of a gas. The necessary air supply is adjusted by means of a mantel impregnated with cerium oxide (CeO) and against which the flame impinges. When there is complete combustion with no excess of air supply the mantel is red, and as soon as the flame changes to an oxidizing flame the color is white, a change which is very delicate with the change of flame. The average composition of the gas must be known and then the air meter can be calibrated in heat units. (c) Raupp's (3) calorimeter is based on the principle of heat conductivity of metals. When heat is supplied to a spot on a solid body, a certain time interval elapses before another spot a fixed distance away rises a given amount. The results are only relative, but for comparative readings will give good approximations.

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(1) Journal Gas Light. 1907, p. 817.
(2) " " " 1906, p. 41.
(3) " " " 1906, p. 107.

Description of Calorimeters Tested.

Of all the gas calorimeters on the market, there are only a few that have been used very extensively or give promise of being so used. These calorimeters are all of the constant pressure type that employ a constant counter current of products of combustion and water separated by a metal wall; all have a gas meter and pressure regulator, and a device for measuring the water heated while a given volume of gas is burned.

The Junkers Calorimeter.

The first successful calorimeter of this type which appeared on the market in 1895 and has enjoyed an excellent reputation was that of Hugo Junkers (1) of Germany.

This calorimeter and its accessories as sold is shown in Fig. I, and a sectional view of the calorimeter is shown in Fig. II. The calorimeter consists of a combustion chamber surrounded by an annular space and a dome. A number of small tubes extend downward from the dome and are set concentric with the axis of the combustion chamber. Above the dome there is a space for water to pass upward to the mixing chamber, supplied with baffle plates. The entire body of the calorimeter is surrounded by an air jacket highly polished outside. The water supply is admitted by the

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(1) Engineering, May 3, 1895, p. 574.

tube (w) into an overhead constant head tank having a weir overflow(a). The pipe(b) allows the overflow to drain. From the constant head tank the water enters the calorimeter by the pipe (f) through the adjustable valve (e), by which the amount entering can be accurately adjusted. Upon entering the calorimeter the water distributes itself around the concentric tubes and rises up over the dome through the mixing chamber and thence out into another tank (c) with a weir overflow. From this point the water is conducted either to the measuring device or to the drains. A thermometer is placed at (e) to register the temperature of the water as it passes into the calorimeter, and another thermometer is placed ath the outlet from the mixing chamber to register the temperature of the water after it has passed through the calorimeter and has been tested. The water capacity of the instrument is about 1600 cubic centimeters.

The gas supply is burned by the bunsen burner (k), having a spreader, in the combustion chamber. The products of combustion rise to the roof of the dome and thence pass down through the concentric tubes and finally out of the calorimeter through the vent (m). The air necessary for combustion enters at the bottom of the combustion chamber. The products of combustion in their course through the calorimeter come in contact with cooler and cooler water until finally when the products escape from the calorimeter they are

room temperature.

The water heated during a test is measured in a large graduated cylinder having a capacity of 2 liters. The water is switched into this cylinder when the pointer on the gas meter passes a given point and at a subsequent position of the pointer on the dial of the gas meter the water is conducted into the waste pipe. So that for a given volume of gas, a known quantity of water has been heated.

The gas for the test is measured in an ordinary wet test meter such as is commonly used for photometric measurements. The water is graduated in liters, but a graduation to 1/10 cubic foot is also available.

A pressure regulator of the weighted bell type takes up any pulsations in the gas due to meter or otherwise.

The Simmance-Abady Calorimeter.

The next oldest calorimeter in practical use is the one devised by Messrs. Simmance and Abady, in England.(1)

The basic principle of this calorimeter is the same as the Junkers, but there aresome changes in the mechanical features which were intended to facilitate the operation. As shown in Fig. III and Fig. IV, The calorimeter consists of a combustion chamber surrounded by concentric

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(1) Engineering, Jan. 13, 1905, p. 66.

annular compartments extending vertically the length of the combustion chamber. These compartments are for holding the water and are connected in series by passages at the top and bottom. The water inlet is at the top of the calorimeter near the outlet for the water, thus bringing the two thermometers on the same level, which is an improvement over the Junkers. The water passes from the inlet chamber down, around and through the series of chambers and finally up over the dome past a thermometer, thence to the outlet chamber to the dumping device. At the outlet chamber there is an open tube in which the water may rise and thus indicate the head of water in the calorimeter. There are no baffle plates below the thermometer to mix the water thoroughly as it passes toward the outlet. The water capacity is about 5 liters.

The upright portion of the calorimeter has a ribbed wooden lagging and the dome has an air space of sheet metal painted black for insulation.

The gas is burned in a bunsen burner and the products of combustion pass up toward the dome and then are deflected down between the annular compartments and out of the calorimeter. Here again the products of combustion leave the calorimeter at room temperature.

The meter for this instrument is of the wet type

and delivers 1/12 cubic foot per revolution and the scale is divided into 100 parts. A table supplied with the outfit enables the operator to translate the meter reading and water measured directly into B. T. U.

A wet pressure regulator of the bell type is connected by iron piping to the meter. This system is a distinct advantage in permanent installations as it prevents leaks and solution of hydrocarbons in the rubber.

As shown in Fig.III, the entire outfit is mounted on a stand and for a permanent installation offers a compact equipment. In this form, however, it is not suitable for field testing.

The scheme for determining the quantity of water heated during the test is similar to the Junkers-- measurement in a graduated cylinder. Here the cylinder holds only 1 liter.

Based on the report of the Committee on Calorimetry, the makers of the Simmance-Abady have abandoned the wood lagging and substituted a polished metal covering, and have added a weir head to the water supply.

The Boys Calorimeter.

Very soon after the Simmance-Abady calorimeter appeared on the market, Mr. C. V. Boys (1) of London, England,

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(1) London Journal of Gas Lighting,--Dec. 19, 1905, p. 808.

perfected the calorimeter named after him. This instrument has been adopted by the London Gas Referees as their standard.

From Fig. VI. it is evident that the Boys Calorimeter differs materially in mechanical construction from any of those described before. The principle of counter currents is still adhered to. The calorimeter consists of three parts (1) a wooden base holding the burners and a portion of the combustion chamber, (2) a polished metal cylinder setting on the wooden base, and (3) the water circulation and absorbing system which fits inside of and rests on the cylinder in (2) and which also fits around the combustion chamber in (1). The water circulatory system consists of a thin walled copper pipe wound in a spiral from the top downward and then back to the top inside of the first coil. This copper spiral coil is made more efficient as a heat absorber and conductor by winding coils of fine copper wire in spirals around the copper coil. Water enters this coil from a constant head tank at the top of the calorimeter and passes through the pipe downward in its spiral path, and then upward in the inside coil to the mixing chamber supplied with baffle plates and then past the outlet thermometer to the measuring device.

Two small lava tip burners serve as the combustion apparatus and the gas burns with a luminous flame. The air

supply is admitted under the cylinder in (2) and thence to the burner. The products of combustion pass upward to the dome of the combustion chamber and thence downwards and around the inside spiral of copper tubing to the bottom of the insulated wall between the inside and outside coils. At this point the products of combustion pass upward and around the outside coil and out of the calorimeter.

The thermometers indicating the temperatures of the water at inlet and outlet are on the same level and side by side, and thus aid the operator to make observations readily. The water capacity of this calorimeter is only about 300 cubic centimeters, and therefore any fluctuations in temperature . . of the water at the inlet or heating value of the gas are quickly observed on the thermometer at the outlet. There is no such lag as in calorimeters with a larger water capacity.

The water heated during a test is measured in a graduated cylinder having a capacity of 2 liters. The switching device for the water is intended to rest on the cylinder and there is no easy means of turning the water into the waste pipe when the test is finished.

The meter with this outfit is a wet test meter and has a capacity of 1/12 cubic foot per revolution and the dial is divided into 100 parts. A table is furnished with this instrument which enables the operator to obtain the proper

factor from the meter reading.

The pressure regulator is of the bell type and is very elaborate. A balanced beam is mounted so that one end is connected with the bell and the other can be counterweighted. A very sensitive regulation can be obtained because the beam is pivoted on wheel bearings.

There is another particular in which this calorimeter differs from the others. The water circulatory system must be lifted off the combustion chamber in order that the gas may be lighted. Then when the test is finished this part must be lifted off again and the coils immersed in a solution of sodium carbonate contained in a special jar so that any sulphuric acid may be neutralized and thus prevent corrosion.

The Sargent Calorimeter.(1)

The Sargent Calorimeter constructed by the Sargent Steam Meter Company is the only American instrument that was available at the time these tests were made. This calorimeter was first offered for sale in 1907 and since then two other models have been constructed embodying various improvements.

The Sargent Calorimeter was intended to combine the good features of the Junkers and the Simmance-Abady cal-

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(1) Progressive Age-- April 15, 1907, p. 206.

orimeters. The instrument consists of a combustion chamber surrounded by an annular space for water through which passes a number of tubes concentric with the axis of the calorimeter. The products of combustion pass upward to the dome and thence down through the concentric tubes out of the calorimeter. The water passes down in the outside compartment, meeting the cold products of combustion, thence up and around the tubes, over the dome past a thermometer, into the outlet. This calorimeter has an automatic electric water dumping device whereby the water is switched every time 1/10 cubic feet of gas is passed.

In Fig. VII and Fig. VIII are shown the first type of Sargent calorimeter. There is no radical difference between this model and that of the Simmance-Abady, except that the water compartments surrounding the combustion chamber are not in series. The first model of the Sargent calorimeter gave inaccurate indications of heating value, due to the fact that the water in passing over the dome toward the thermometer was not properly mixed, owing to the absence of baffling plates. Prof. J. C. Dickerman, of the Chemical Engineering Department of the University of Wisconsin first noticed this defect and discovered that a stream of hot water from the middle of the dome rose under the thermometer and thus gave a reading on the thermometer that was not the

average temperature.

Upon his recommendations, a second model, shown in Fig. IX and Fig. X, was constructed, having a capacity of about 2 liters. Here there is a constant head with weir overflow for the water supply and there is also a constant head and weir overflow at the outlet with a cock at the outlet to regulate the rise in temperature of the water heated. Baffle plates are also inserted above the dome to mix the effluent water thoroughly. The dome has a polished metal jacket with an air space underneath for insulation. The upright portion is insulated with wood lagging. It was this model of this calorimeter that was used in the following tests.

As a result of the findings in the following tests the Sargent Steam Meter Company has constructed a new model embodying the recommendations made to the American Gas Institute by the Committee on Calorimetry. The last model has not been tested yet, but Fig. XI shows the new model has the good features of the Junkers and the Simmance-Abady calorimeters.

To determine the quantity of water used in each test, the water is caught in copper buckets and weighed on a platform scale sensitive to 1/100 pounds.

The meter is the usual wet test meter. Each revo-

lution of the drum corresponds to 1/10 cubic foot and the dial is divided into 100 equal parts. At each revolution the pointer on the dial makes contact with a spring and completes an electric circuit which operates the water dumping device. This is intended to eliminate the personal equation.

The original pressure regulator was attached to the outlet of the meter and was of the diaphragm type. The diaphragm was made of a thin rubber sheet, and by means of a small thumb screw on the diaphragm the pressure could be regulated.

The latest model of this calorimeter includes the regulation wet pressure regulator of the bell type.

Determination of Heating Value at Constant Pressure.

Since gas is sold in the United States at a certain price per cubic foot, and since the metric system of measures is not in common use, it appears desirable to express the heating value of the gas in the so-called English units, the cubic foot, the pound and the British Thermal Unit. The British Thermal Unit is that quantity of heat absorbed by 1 pound of water raised 1 degree Fahrenheit at its maximum density 39.1°F. The heating value of a gas as determined at constant temperature is commonly expressed in terms of the amount of heat absorbed by a given number of pounds of water which has been heated a given number of degrees Fah. Since the heat in a given quantity of water is the product of the weight and specific heat of water, and the rise in temperature, it is necessary to know the unit of specific heat of the water. The specific heat of water is commonly placed at 1.000, but the temperature at which this is true is not uniform. Thus Regnault gives the standard temperature at 32°F. Rowland (1) uses 69°F, so also do Ludin (2) and Griffith. (3) There is only a slight error introduced by neglecting the change in specific heat with the temperature. The specific heat at 32°F = 1.0000, but here, in order to

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(1) Am. Jour. Arts & Sciences, 1879.
(2) Inaugural Dissertation, Zurich, 1895.
(3) Phil. Mag. Nov.,1895.

conform with the standard temperature set for specific heat of water, the standard temperature for gas is assumed at 60°F. Gas as metered is assumed to be saturated with water vapor, and hence a cubic foot of metered gas contains less than a cubic foot of dry gas. The volume of a gas varies inversely with the pressure and directly with the temperature. The volume of dry gas varies directly as its partial pressure. Hence the volume dry under standard conditions of a given volume of metered gas is expressed as:

$$V_1 = V_2 \frac{h-a}{h} \times \frac{520}{460+t} \times \frac{h}{30 - .517} = V_2 \frac{17.64\ (h - a)}{460 + t}$$

where V_2 = volume of metered gas, h= barometer in inches of mercury a = vapor tension at temperature (t) of gas. The expression $\frac{17.64\ (h - a)}{460+t}$ is called the correction factor. The heating value of a gas dry under standard conditions therefore in B. T. U. per cubic foot is expressed as:

$$\frac{\text{Weight water X rise temp. in F}^\circ}{\text{Vol. gas used x correction factor}}.$$

The heating value as given in this expression is commonly called the "gross" or total heating value. If from this value there be subtracted the latent heat of condensation of the water formed during combustion, the result is called the "net" heating value. At the gas conference held in Madison in March, 1908, the concensus of opinion seemed to be that the "net" heating value is not a true

measure of the value of the gas. Since the amount of condensation depends upon the state of the humidity of the air and gas supply and the temperature at which the products of combustion leave the calorimeter, the "net" heating value can be a widely varying quantity. This question is also discussed in the report of the Committee on Calorimetry in the Proc. Am. Gas Inst., Vol. III, p. 292.

It is apparent from the above expression that the accuracy of the heating value will depend on the accuracy with which the data can be obtained.

There are two means of obtaining the quantity of water heated:--(a) by measuring the volume and (b) by weighing. In all the calorimeters in common use a considerable quantity of water is used for each test, and any small error made in its estimation will produce but a slight error in the final result. From 4 to 8 pounds of water are commonly employed for a test. A suitable measuring device for these quantities would necessitate a comparatively large vessel and an error is easily made in observing the correct level of water. A weighing device can be easily obtained that will give the weight to within an extremely small error. Another error is made by the operator failing to admit the water to the measuring vessel as soon as the test begins and also failing to shift the water from the measuring device

when the test is ended. A little practice, however, will enable one to become very expert in shifting the water.

It seems to be a convenient and common practice to use from 0.1 to 0.2 cubic feet of gas for a test, measured by a wet test meter. Any small error made in measuring the 0.1 or 0.2 cubic feet will be multiplied by 10 or 5 respectively when the heating value per cubic foot is computed from this data. It is important, therefore, that the meter be carefully calibrated, the water saturated with the gas to be metered, the gas saturated with water vapor before passing through the meter, and the meter should stand perfectly level. It is further important that the metered gas be delivered in a steady and constant volume to the burner during the test, and a pressure regulator should be placed between the meter and burner to produce these conditions.

It is of highest importance for accurate work that the rise in temperature of the water heated during a test should be accurately determined. Since there are two thermometers used for this purpose, and since the reading of the thermometer at the outlet for the water is not steady, it is necessary that accurate readings be taken at both instruments, and that the thermometers give equal movements of the mercury thread for the same temperature interval. Suppose there is a temperature difference of 15°F between the water at the inlet and outlet of the calorimeter, and suppose th

an error of 0.1°F is made in the observation of that rise. Then for a gas having 600 B.T.U. per cubic foot an error of 4 B. T. U. is made.

For close work it is necessary that the temperature of the gas be determined accurately, that the gas enter the meter saturated with water vapor, and that the barometer be read accurately. Many commercial test meters have thermometers that are graduated to 2°F and are not at all accurate, and any sort of accurate work with these is impossible.

CHAPTER IV.

Calibration of Instruments.

Because the accuracy of the determination of the heating value of a gas depends so largely on the accuracy of the measuring devices, all water weighing buckets, meters, and thermometers were accurately calibrated before using them to make tests on the various instruments.

In all the tests of this investigation the quantity of water used for test was determined by weighing in copper buckets. A sufficient number of these buckets to supply each calorimeter were available, and they were all made the same weight so that a common counter-balance could be used. The water was weighed on a torsion balance sensitive to 0.001 of a pound in 10 pounds. Each bucket with the inside wet was carefully balanced against the counterweight. This was done to facilitate weighing later on. Before balancing the wet bucket it was shaken in an inverted position for about 5 seconds to remove the drip.

The meters used in the tests were all calibrated against a 1/4 cubic foot bottle which had previously been calibrated by weighing the volume of distilled water at 62°F contained in the bottle. With this device all meters were regulated to an accuracy of 0.05%; each test on the meter consisted in passing 0.5 cubic feet of gas through at the rate to be used subsequently, which necessitated two fill-

ings of the bottle.

Meters.

The calibration of the meters to give a constant registration presented many difficulties due to the construction of the various meters. The Junkers meter has an opening in the casing for the addition of water and another opening at the side which connects to a weir overflow. There is no gauge glass and it is impossible to tell what the level of the water is as the weir overflow is not at all sensitive. Upon adding water to the meter some of it would get ledged in the drum and after a few revolutions the meter showed a different calibration than for the first, because the water had become dislodged from the drum. The use of this meter was finally abandoned, due to the above difficulties. No attempt was made to use the meters supplied with the Boys and Simmance-Abady calorimeters, for the meters registered 1/12 cubic foot and the gauge glass for the water level was so large that it would be impossible to set the water accurately, as proved by experience with the Junkers. The meter supplied with the Sargent calorimeter proved to be satisfactory with the exception of a few minor details, as a water level marker in the gauge glass. This marker was too frail and was abandoned. A marker on the outside of the gauge glass is desirable. The meter manu-

factured by the American Meter Company was very satisfactory in almost all respects.

Thermometers.

It was necessary to calibrate all thermometers accurately in order that comparative tests should give true relative efficiencies. The standard thermometers were--#2620, of the Physics Department of the University of Wisconsin, having a range from 0° to 100°C, graduated to 1/5°C, and #4180 of the Chemistry Department of the University of Wisconsin, having a range of 0° to 100°C, and graduated to 1/10°C. Both thermometers had calibration certificates, #2620 from the U. S. Bureau of Standards, January 14, 1908, and #4180 from the German Bureau of Standards, August 9, 1902. The calibration curves of these thermometers are given in Plate 1. A comparison of the ice points of the two standards showed that #4180 read 0.08°C high. With this correction the two thermometers agreed in the interval from 10 to 50°C. Since thermometer #4180 was graduated to 1/10°C and had a good open scale, it served as the standard.

The standard and two thermometers to be calibrated were hung side by side immersed in water to the depth at which they were to be used. The water was agitated continuously by means of a stirrer to insure a uniform temperature. The thermometers were read with the aid of a large magnify-

ing glass by two observers who made independent readings. A piece of plate glass served as a shield between the observer and the thermometer. In this manner calibration curves were obtained for six Sargent Steam Meter Company thermometers having a range of 65° to 110°F and graduated to 1/10°F, and two centigrade thermometers with a range of 0° to 50°C and graduated to 1/10°C, belonging to the Milwaukee Gas Light Co. Junkers Calorimeter. The calibration of these thermometers shows a wide variation in the bore of the capillary, making in some cases an error of over 0.2°F which would cause an error of 8 B. T. U. on a 600 B. T. U. gas. A few of the calibration curves are shown in Plate II to illustrate the variation in calibration of the different thermometers.

Since the publication of the investigation on calorimeters in the Proceedings of the American Gas Institute, Vol. III, 1908, Mr. R. B. Brown of the Milwaukee Gas Light Company, obtained some stem thermometers from Hohman, Maurer Co., of Rochester, N. Y. These thermometers were made according to the specifications of Mr. Brown, and have a range from 65°F to 115°F, are graduated to 1/10°F, and have an auxiliary division at 32°F. The thermometers have been carefully made and have a bore that is very accurate. They were calibrated against each other, by immersing them

completely in a bath of water whose temperature could be regulated to any point desired. The calibration curve of these thermometers is shown in Plate IIa where the variations in comparative indications are plotted against the readings of one of these thermometers The error is small and for most commercial purposes may be entirely neglected.

Arrangement of Apparatus for Tests.

It was evident after the calibrations of the various instruments had been made that certain devices were unsuitable for fair tests of the calorimeter and the calorimeter outfits were therefore arranged so that each would operate under the most efficient conditions.

Water Supply.

The water for the tests was taken from Lake Mendota and was clear and was free from suspended matter. A tank of about 60 cubic feet capacity located about 40 feet above the calorimeter served to supply the necessary water and give the required head, and each calorimeter had a separate supply cock. During the summer this water had acquired the temperature of the atmosphere, while in the winter the water was heated to room temperature before passing into the calor imeter. A very satisfactory heating device consisted of a 5-gallon jar fitted with electrodes and filled with a solution of sodium sulphate, through which an alternating current passed. The solution was agitated continuously with a motor driven stirrer. A copper tube about 1/4 inch internal diameter was wound in a spiral and connected in series with the calorimeter water supply tubing from the main cock on the water pipe. The water supply to the calorimeter in passing through the copper coil immersed in the electrolyte could be heated to any desired temperature and kept at any

desired temperature within 0.1°F by proper regulation of the electric current through the electrolyte.

Gas Supply.

An accurate test of calorimeters requires a gas supply of sufficient volume and of uniform composition. Large quantities of pure elementary gases were not available, so the gas supply was drawn from the city service mains and stored in two holders, each having a capacity of 60 cubic feet. From these holders the gas was supplied to each of the calorimeters through a separate service cock. A Connolly Governor in the line between the holders and calorimeters served to keep the pressure uniform.

Arrangement of Calorimeters and Accessories.

It did not seem fair to make the comparative tests on the calorimeters with the outfits as they are commonly sold, but each calorimeter was so installed that its highest efficiency would be attained.

In the Junkers calorimeter outfit, the regular meter was not used, owing to the impossibility of making it check the other meters. A meter made by the American Meter Company was substituted. Instead of using the 2-liter measuring cylinder for the water, the copper buckets were used. The Junkers arrangement, then, consisted of the regular calorimeter body, the wet pressure regulator, and the American Meter Co. meter.

The Simmance-Abady instrument required changes also. The water shifting device shown in Fig. III. was discarded because it was too inconvenient for the operator to make accurate determinations of the water with it. In the place of the regular device a rubber tube was fastened onto the outlet pipe to the weighing bucket. With the original device it was impossible to maintain a constant head in the pressure gauge pipe at the outlet; with the scheme used a constant head was easily maintained, by putting a screw pinch cock on the rubber tubing, and a steady stream of water flowed without spattering. The regular meter could not be used, and a meter built by the Sargent Steam Meter Co. took its place. The pressure regulator was retained as it gave good satisfaction.

Some changes were necessary on the Boys calorimeter also. The inlet and outlet pipes for the water supply are too small and it was necessary to slip the stopper through where the thermometer was inserted, over the pipes instead of inside as was intended. This procedure was necessary because the space for the stopper and thermometer was so small that when they were inserted inside the water had no chance for easy escape into the measuring device, and would be prevented from escaping if the stopper were inserted too far. The water measuring cylinder was replaced by the weighing buckets. The meter was replaced by a Sargent

Steam Meter Company meter, because the regular meter was graduated to 1/12 cubic foot and could not be brought to the required calibration. The regular pressure regulator was replaced by a Junkers regulator, because the Boys had so many parts that it was impossible to prevent or stop leaks.

The second Sargent Calorimeter was used for the tests and is shown in Fig. IX and Fig. X. The body of this calorimeter was not changed but changes were necessary on the pressure regulator. This regulator was of the rubber diaphragm type and its greatest defect consisted in being subject to leaks. Much time was consumed in trying to make this regulator tight, and it was discarded in favor of a Junkers wet regulator. The Sargent diaphragm regulator has too many parts and joints and herein lay the defects. The automatic water shifting device was not used, because it was thought that with practice the operator could shift the water as accurately by hand as the automatic device would shift it.

The entire set of calorimeters as operated is shown in Fig. XII.

CHAPTER VI.

Nature of Tests.

For each series of tests on the calorimeters the gas tanks were filled with a fresh supply of gas from the city mains and allowed to stand until the gas had reached a homogeneous composition. All tests were run in series which were numbered and a new series started with each fresh supply of gas in the tanks. Tests on the different calorimeters of each series were made as nearly simultaneous as possible. Before beginning any series of tests, the gas conduits were tested for leakage, then the lighted burner inserted in the calorimeter, and the water supply adjusted to give a rise of approximately 15°F. During each series of tests the humidity of the atmosphere was determined by a wet and dry bulb thermometer upon which a current of air was directed. The data from each test were recorded on blanks printed for this investigation and facilitated the tabulation and computation.

1. Preliminary tests.

The series of tests from A to D were made for the purpose of becoming familiar with the operation of the instruments. In these series it was determined what position of the damper governing the rate at which the products of combustion left the calorimeter, gave the highest heating value of that sample of gas. During subsequent tests the dampers were kept in this position. No statement can be

at which position the damper should be set for all sorts of gas, because the air supply for different compositions of gas varies, and thus every operator should determine the position of the damper for his own calorimeter.

The Boys calorimeter has an open flame burner and it gave a great deal of trouble by depositing soot on the walls of combustion during a high rate of combustion. The open flame burner was replaced by a small Bunsen burner which gave very satisfactory results and was used on subsequent tests.

In one of the series water was accidentally spilled on the wood lagging surrounding the Simmance-Abady, and Sargent Calorimeters. The results of this series indicated that evaporation had been taking place and the heating value had been lowered. It seemed undesirable therefore to employ a wood lagging.

It was found that the use of only 0.1 cubic foot of gas per test introduced too large an error, but that 0.2 cubic foot would give consistent results and therefore this quantity was used in all subsequent tests.

Of the various problems, one that presented itself almost immediately was to determine what rate of combustion would give the maximum heating value. Several series of tests at first showed no uniform variation and the reason

for this became apparent when a thermometer graduated to 1/10°C was used in place of the thermometers furnished with the meters which were graduated to 2°F. A proper change of the correction factor with a change in temperature produced perfectly uniformly varying results. It is necessary, therefore, that the thermometer indicating the temperature of the gas should be accurate and be graduated to at least 1°F.

The Maximum Rate of Combustion.

Each calorimeter was tested to determine what rate of combustion gave the highest heating value for a given sample of gas. Results show that each calorimeter has its own maximum rate of combustion. These results are given in Tables 1 to 5, and are shown graphically in Plates III to VII. Table 1 and Plate III (Series E) show that for the Junkers #372 belonging to the Chemical Engineering Department the most efficient rate of combustion is from 7 to 8 cubic feet per hour. Subsequent efficiency tests on two other Junkers calorimeters seem to indicate that this rate would hold for all Junkers.

Table 2 and Plate IV show that the Boys calorimeter using a bunsen has its maximum rate of combustion at about 4 cubic feet per hour. In the "Notification to the Metropolitan Gas Referees For the Year 1908" the rate is given as 5 cubic feet per hour, with the open flame burner.

This investigation seems to point to the fact that a rate of 5 cubic feet per hour with an open flame burner on a 600 B. T. U. gas will not give the most efficient results.

It was exceedingly difficult to obtain satisfactory results with the Simmance-Abady calorimeter because of the wide variation in the consecutive tests. The reason for this lack of constancy will be explained later. Two series of tests were to determine the maximum rate, one with the regular burner supplied with the calorimeter, and the other with a bunsen burner without the spreader from a Junkers instrument. Table 3 and Plate V (Series H) show that with the regular burner the maximum rate of combustion is about 4.2 cubic feet per hour, while with the Junkers burner the maximum rate is about 7 cubic feet per hour, as shown in Table 4 and Plate VI (Series S). The Junkers burner was in the same relative position at which the regular burner stood normally. The only reason that seems apparent is that the Junkers burner had a larger capacity than the Simmance-Abady. The wide variation in results at the same rate of combustion in the tests shown in Plave V indicate that the calorimeter is not operating as an efficient instrument.

Several series of tests were made on the Sargent calorimeter before satisfactory results were obtained. In Table 5 and Plate VII (Series S) are shown that the maximum rate of combustion is about 5.5 cubic feet per hour. The

results of Series G and H check this value fairly well. These tests are not tabulated because the results are not uniform.

In operating any calorimeter it is highly desirable that the operator make a series of tests with the particular quality of gas he has available and determine the maximum rate of combustion. With a low heating value gas the rate of combustion must be higher than with a gas having a high heating value.

Comparative Efficiency.

One of the principal objects of this investigation in regard to the needs of the Railroad Commission was to determine the relative efficiency of the calorimeters when burning the same sample of gas at the most efficient rate of combustion for each instrument. A sample of 120 cubic feet of gas served to make this test, and the four instruments,--Junkers #872, the Boys, the Simmance-Abady and the Sargent, operated simultaneously. The tests on each of the instruments were made as nearly at the same time as possible, there being an operator for each calorimeter. The temperatures at the inlet and outlet of water supply were observed as frequently as it was possible to do so, and all precautions were observed to give the maximum heating value from each calorimeter. The results of this series of tests are shown in Table 6 and Plate VIII Series I.).

The Boys calorimeter was operated with a luminous flame, in order that a fair test be made with the instrument as sold.

The curves of relative efficiency in Plate VIII show a gradual decrease in heating value of the gas. One of the gas holders was filled with water that had been saturated with coal gas, and the gas used for the test was a carburetted water gas. It is possible that some of the illuminants in the gas were absorbed by the water in the holder. In Plate VIII the time of making the tests is plotted as abscissae and heating value as ordinates. The results show that the Junkers and Simmance-Abady give higher results than the Sargent and Boys. The Junkers gave the most consistent results, while the results on the Simmance-Abady are extremely irregular, but average fairly close to the Junkers.

Subsequent tests on the Simmance Abady for absulute efficiency pointed to the fact that the calorimeter had not been operated in such a manner that the true conditions were brought out. The temperature of the water at the outlet varied excessively, in some cases as much as 1°F and it was impossible for one operator to observe and record the extreme fluctuations which were caused by insufficient mixing of the outlet water before reaching the thermometer.

Another series of tests was made on the Junkers

#872 and the Simmance-Abady. In this series two operators were stationed at the Simmance-Abady, one to observe the temperatures and shift the water and the other to record the data. Observations of the outlet water temperature were made and recorded as rapidly as possible, and during a test lasting nearly 3 minutes about 40 observations of the outlet temperature were made against 10 observations in the same time in Table 6 (Series I). A very different result of the comparative efficiency between the Junkers #872 and the Simmance-Abady is apparent from these tests which are shown in Table 7 and Plate IX (SeriesP). The heating value on the Simmance-Abady is about 627 B.T.U., against 575 B.T.U. on the Junkers. The temperature variation at the outlet on the Simmance-Abady was excessive; as shown in test P-3, where the extremes were 86.72°F and 85.80°F, respectively.

Since several Junkers calorimeters were available it was thought desirable to run comparative tests on them. These instruments were:--#872, belonging to the Chemical Engineering Department, #571 belonging to the Steam Engineering Department (both of the University of Wisconsin), and a third Junkers belonging to the Milwaukee Gas Light Company. This last instrument was so modified that the thermometers indicating the temperatures of the water at the inlet and outlet were on the same level as shown in Fig. I.

Comparative tests on these three instruments as recorded in Table 8, Plate X (Series M) showed a close agreement between #872 and #571, but there is a discrepancy between #872, #571 and the modified M. G. L. Co's Junkers. A subsequent recalibration of the meters used in the M.G.L. Co. Junkers showed an error of 0.4% fast. Making the correction on the average reading of this series by the Milwaukee Gas Light Company's Junkers, there is still a difference of 0.4% between the readings of the M.G.L.Co. instrument and #872 and #571. This difference is very small and is perhaps due to an error in the thermometer, for an error of 0.4% means 2.5 B. T. U. and an error of 0.05°F would produce an error of about 2.5 B.T.U. The tests show, however, that the three Junkers calorimeters are in close agreement for practical purposes and that the instruments are built alike.

Absolute Efficiency.

The preceding series of comparative tests, while showing what calorimeter gives the highest heating value on a given sample of gas, does not show which calorimeter gave the correct heating value. Hence a determination of the absolute efficiency was necessary.

Some investigation had been made on the Junkers calorimeter to determine its efficiency as a scientific and

commercial instrument. Dr. Theodor Immenkötter,(1) who burned hydrogen in the calorimeter and computed the thermal balance from his observations, found that the calorimeter was about 99.70% efficient.

It occurred to the writer that the use of an electrical heating device would afford a simple and accurate means of determining the amount of heat energy supplied in a known time interval, and the heat absorbed could be determined in the usual way.

The heating device consisted of a coil of nickel wire wound on a mica frame and mounted on a suitable holder which could be fastened in the calorimeter in the same manner as the bunsen burner. This coil is shown in the photograph in Fig. XIII.

The energy necessary to heat this coil was supplied by a 120-volt storage battery set, and was measured by standard electrocal instruments. These instruments were of the "Weston Laboratory Standard" type and had been calibrated recently. The current through the coil was regulated by means of a lamp bank placed in series with the coil, and the amount of energy supplied was sufficient to give the same

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(1) "Über Heizwerthbestimmungen mit besonderer Berücksichtigung gasförmiger und flüssiger Brennstoffe." -- Press of R. Oldenbourg, Berlin, 1905.

(") Gas World-- Feb. 10, 1906, p. 285.

rise of temperature to the same quantity of water that was used when testing with gas. Since the voltage drop across the coil is over 90 volts, the lamps therefore do not glow, and thus introduce no error in heating the calorimeter. The arrangement of this apparatus is shown in Fig. XIV.

Three operators were employed in making these tests, one each to observe and record the voltmeter, ammeter and calorimeter readings, respectively. The time of test was three minutes, and during this period the data were taken by each operator as fast as each could record the same. The water used during each test was weighed to within one gram as the result was to be expressed in small calories.

The energy input is the product of volts, amperes, time in seconds, and the equivalent of a watt-second in small calories. The energy absorbed is the product of water heated, in grams, times the rise in temperature in degrees Centigrade. The efficiency then is the ratio of heat absorbed to heat supplied.

Such absolute efficiency tests were made on the Junkers #872, the Simmance-Abady, and the Sargent Calorimeters. It was not possible to use this particular coil in the Boys and so no test was made. Tables 9 and 10 and Plates XI (Series K & L) show the results on the Junkers and Simmance-Abady, and Table 11 and Plate XII (Series T) show the results on the Sargent. The Junkers #872 and the Sargent

show results of about 99.5% efficiency, and this result on the Junkers checks very closely the results obtained by Dr. Immenkötter. The tests on the Simmance-Abady show an average of 106% efficiency..

From these results it is at once apparent why the Simmance-Abady calorimeter gave a higher heating value than the Junkers #872 as shown in Plate IX. If the average heating in Plate IX is 629 B. T. U , and if the correction of 106% is applied, it will give 592 B. T. U. for the Simmance-Abady, and if the proper correction be applied to the Junkers a value of 582 B. T. U. is obtained. This still leaves the Simmance-Abady value 10 B. T. U. high. This discrepancy may easily be accounted for by the fact that during the absolute efficiency test with the electric heater, the operator could not record so many outlet temperatures of the water on the Simmance-Abady as was possible in Table 7 (Series P) when there were two operators. In the tests shown in Table 7 (Series P) the Simmance-Abady gave much higher values than the Junkers, than were found in the tests shown in Table 6 (Series I). In Series P the temperature at the outlet was taken more frequently than in Series I, and hence more accurately. Had the temperatures at the outlet on the Simmance-Abady been taken in Series L as frequently as in Series P, the average rise would have been higher and hence the apparent heat absorbed and the efficiency would

have been higher. The discrepancy, then, between Series L and Series P would have been much smaller.

It is not apparent why the Junkers #872 should give a higher heating value on the same sample of gas than the Sargent, as shown in Plate VIII, when the absolute efficiency of the Sargent is about equal to that of the Junkers, as shown in Plate XI and XII.

After the efficiency tests had been made, it became apparent that there were other factors that would govern the accuracy with which a heating value test could be determined with a given calorimeter. All the subsequent tests were made on Junkers calorimeter #872 in the Chemical Engineering Laboratories.

Variation of Heating Value
With Rise in Temperature of Water at Outlet.

In all previous tests the rise in temperature of the water at the outlet over the inlet was fixed at approximately 15°F. This temperature was chosen because a quantity of water was delivered that nearly filled the weighing bucket whose capacity was about 8.5 pounds. The purpose of this series of tests is to determine what changes, if any, are made in the determination of the heating value when the temperature of the water at the outlet is raised to various points above the temperature at the inlet. The water supplied to the calorimeter was brought to room tem-

perature in the heating coil, described before, and kept at this temperature during the test. All other temperatures and conditions were maintained constant excepting the temperature at the outlet. The rise in temperature was controlled by the valve at the inlet which permitted a close regulation. The results of this series are shown in Table 12 and Plate XIII(Series Z). The change in heating value is only small, less than 1%, and shows that the thermal efficiency of the Junkers is high. The small difference in temperature between the esdaping products of combustion and the room and water at the inlet will hardly account for the variation. As will be shown later, the difference is due to radiation losses in the calorimeter. It is apparent that to obtain the highest heating value the rise in temperature of the water should not be greater than 15°F. A small error made in switching and weighing a large quantity of water introduces only a small error in the final result, but a small error with a small quantity of water gives a large percentage error.

Variation of Heating Value With Temperature Difference Between the Room and Water at Inlet.

In many places where a calorimeter is installed, the water supply is taken directly from the city service mains. In the winter the water is much colder than the

room, and this is especially true in a cold climate. What is the error which is introduced where water is used that is much below room temperature? In other cases the water supply may be much warmer than the room, especially where the supply pipe passes through a warm room, as where the supply is heated in some other manner. The purpose of this series was to determine the error that arises when the water supply is not the same as the temperature of the room.

The Junkers calorimeter #872 was again used and the apparatus arranged in all respects like the other tests, except that the supply water passed through a copper coil immersed in an electrolyte. This arrangement permitted the cooling of the water nearly to its freezing point and also heating it to any desired temperature, and holding the water at the desired temperature for any desired length of time.

The room temperature was practically constant for it varied only from 68°F to 70°F, and the temperature of the water varied from 40°F to 90°F. The rise in temperature of the water at the outlet over the inlet in all tests was approximately 15°F, and the rate of condensation about 7 cubic feet per hour.

The results of these tests are shown in Table 13 and Plate XIV (Series X). The heating value gradually decreases as the temperature of the water at the inlet ap-

proaches and surpasses the temperature of the room. Below room temperature the curve bends down, and above room temperature the curve bends up. The change in heating value is much slower below than above room temperature. There is a point of inflection in the curve and at that point would be the temperature at which the calorimeter should be operated to get correct results.

Thermal Balance of Tests in Series "X".

The exact point of inflection of the curve in Plate XIV is not at once apparent and it became necessary to analyze the sources of loss and gain at the various temperatures. If the proper corrections were made at each temperature, the resulting curve should be a straight line, since the sample of gas was homogeneous and the calorimeter constant in its operation. The sources of error are (1) radiation or absorption of heat by the calorimeter body, (2) the sensible heat in the air and gas supplied and the products of combustion, (3) the latent heat in the vapor carried by the products of combustion.

1. Heat Absorbed or Radiated by the Calorimeter.

That heat is absorbed from or radiated to the atmosphere by the calorimeter is due to the fact that the water supply entered the instrument at temperatures ranging from 30°F less than room temperature to 20°F more than room temperature. These various amounts of heat are determined

by allowing the water to flow through the calorimeter without having any flame inside, but having the combustion chamber and vent for the products of combustion exactly as in the other tests. The temperatures at the inlet and outlet were then taken and it was observed that when water colder than the air flowed through the outlet temperature was greater than the inlet, and when the water at the inlet was warmer than the room the outlet thermometer showed a lower temperature. The average amount of water passed while 0.2 cubic feet of gas could be burned at the rate of 7 cubic feet an hour was 7.339 pounds. Then per cubic foot of gas the total water would be 36.95 pounds. The heat absorbed or radiated per cubic foot of gas burned is therefore the product of 36.95 and the change in temperature. The data and computations are tabulated below:--

Temp. at Inlet F°	Pounds water passed/cu.ft.	Change in Temp. C°	B. T. U. per cu.ft.	How disposed.
40.0	36.95	+ 0.135	+ 8.99	Absorbed.
53.3	36.95	+ 0.058	+ 3.83	"
59.4	36.95	+ 0.044	+ 2.90	"
70.1	36.95	- 0.002	- 0.13	Radiated.
79.2	36.95	- 0.001	- 0.06	"
88.7	36.95	- 0.79	- 0.79	"

These results are plotted as curve "A" in Plate XV with the temperatures of inlet water as abscissae and the heat absorbed or radiated as ordinates. At 40°F there are 8.99 B.T.U. absorbed; at 70°F heat is neither absorbed nor radiated, and at 90°F there is about 0.8 B.T.U. radiated. This curve gives one reason why the water supply should be at the temperature of the room, for then there is a balance.

2. The Heat Balance of Incoming and Outgoing Gases.

The heat balance between the dry incoming and outgoing gas can only be obtained from an analysis of the combustible gas and the products of combustion from which data the air supplied for combustion and the volume of the products of combustion can be computed. The combustible gas and the air supply bring in a given amount of sensible heat constantly since the gas and air temperature did not vary appreciably during the test.. At different stages in this series of tests the products of combustion leave at temperatures different from the respective gas andair temperatures, and therefore heat is either absorbed or radiated, depending on whether the products leave at a lower or higher temperature, respectively, than the incoming gases. Since the combustible gas is composed of some hydrocarbon gases whose combustion forms water vapor, therefore a cubic foot of dry combustible gas burned with the reouired amount of dry air will in general form a smaller volume than the combined vol-

ume of incoming gases. If then the incoming gases and the products of combustion, both dry, were at the same temperature, the total sensible heat in the incoming gases is still higher than the heat in the products. It is upon these facts that the following computations were based.

(a) The Gas Analysis.

The analysis as reported is on the basis of saturated gas at 29 inches of mercury and 68°F. The volume of dry gas in a unit volume of the sample taken is expressed by the equation $V = V_1 \frac{h - a}{h}$ where V = vol. dry, V_1 = vol. wet (h) = barometer in inches of mercury, and (a) = vapor tension at 68°F in inches of mercury. One cubic foot of saturated gas is equivalent, then, to $1 \times \frac{29.00 - 0.68}{29.00} = 0.976$ cu. feet. If the percentage composition of each constituent in the saturated gas be divided by 0.976, the percentage of that constituent in a dry gas is obtained.

The combustible gas has the following analysis:-

Component	% Wet	% Dry
CO_2	3.90	4.00
Illum.	10.70	11.00
O_2	0.10	0.10
CO	32.30	33.10
CH_4	17.20	17.61
H_2	29.6	30.30
N_2	3.8	3.89
H_2O	2.4	
Total	100.00	100.00

The product of combustion has the following analysis:-

Component	% Wet	% Dry
CO_2	14.0	14.35
O_2	2.0	2.05
N_2	81.6	83.60
H_2O	2.4	
Total	100.00	100.00

(b) The Air Supplied and the Volume of Products of Combustion.

Since the gas was burned completely and since the composition is known the air required for its combustion is easily computed. It is assumed here for want of more definite information that the "Illuminants" are ethylene C_2H_4. The average humidity of the air supply is 62%.

			Products.		
Gas	Cu. Ft. Vol.	Oxygen needed	CO_2	H_2O	N_2
CO_2	0.04	----	0.04	----	----
C_2H_4	0.11	0.33	0.22	0.22	
O_2	0.001	-(0.001)			
CO	0.331	0.165	0.331		
CH_4	0.1761	0.3522	0.176	0.352	
H_2	0.303	0.151	----	0.303	
N	0.0389				0.0389
Total	1.000	1.009	0.767	0.875	0.0389

The 1.007 cubic feet of oxygen supplied is equivalent to 4.84 cu. ft. of dry air of which 3.83 cu. ft. are nitrogen.

In the combustion of 1 cu. ft. of dry gas 0.767 cu. ft. of CO_2 are formed. 1 cu. ft. of CO_2 weighs 1.965 oz. and hence in 0.767 cu. ft. CO_2 there are 0.411 oz. of carbon. The 0.411 oz. C required 0.767 cu. ft. of O_2 which is equivalent to 3.69 cu. ft. air. 1 oz. C in the gas requires $\frac{3.69}{0.411}$ = 8.98 cu. ft. dry air for its complete combustion.

In one cu. ft. of the products of combustion there are 0.143 cu. ft. of CO_2 which contain 0.075 oz. C. and which requires 0.143 cu. ft. of O_2. There are 0.02 cu. ft. of free O_2 in each cu. ft. of products of combustion, and 0.143 cu. ft. of O_2 combined with C. The total O_2 per 0.075 oz. C = 0.163 cu. ft., which are equivalent to 0.77 cu. ft. of air. Therefore for each oz. of C in the products of combustion there are $\frac{0.77}{0.75}$ = 10.25 cu. ft. air.

Since for 1 oz. of C 8.98 cu. ft. air are required and 10.25 cu. ft. are supplied, the excess air is 14.3% and hence there are 4.84 x 1.143 = 5.33 cu. ft. dry air supplied per cu. ft. of dry gas.

The volume of the products of combustion of 1 cu. ft. of dry gas is 3.87 cu. ft. N_2 + 0.767 cu. ft. CO_2 + 14% excess of air = 3.87 + 0.767 + 0.691 = 5.228 cu. ft. dry.

(c) The Sensible Heat in The Dry Gases.

The specific heat of the dry combustible gas computed from the analysis is 0.01175 B.T.U per cu. ft. The specific heat of dry product of combustion is 0.01123 B.T.U. per cu. ft.

At 70°F the sensible heat
in the gas =

1 x 0.01175 x 70 = 0.8225 B.T.U. per cu. ft.

At 70°F the sensible heat
in the air =

5.53 x 0.0106 x70= 4.130 B.T.U. " " "

Total heat in dry gases
entering the calorime-
ter constantly =

4.952 B.T.U. " " "

The volume of the dry product at 70°F is 5.228 cu. ft. and this volume will change with the temperature of the inlet water. This sensible heat in the dry products at each temperature of the escaping products will be the volume at that temperature multiplied by the specific heat per cu. ft., 0.01123, and by the temperature at which the products escape from the calorimeter.

The heat gained or lost by the calorimeter at each different temperature of the inlet water is then the difference between the sensible heat of the incoming gases and the sensible heat in the outgoing gases. These data and computations are tabulated below.

TESTS	EXIT TEMP.	VOL. OF PRODUCT IN CU.FT	B.T.U. SENSIBLE HEAT IN PRODUCT	B.T.U. SENSIBLE HEAT IN SUPPLY	B.T.U. GAINED	B.T.U. LOST
1 -4	45.9°F	4.99	2.58	4.952	2.37	
5 -8	54.1°F	5.07	3.07	4.952	1.88	
9 -12	63.3°F	5.16	3.64	4.952	1.31	
13-16	72.0°F	5.25	4.25	4.952	0.70	
17-20	81.5°F	5.34	4.88	4.952	0.07	
21-24	88.5°F	5.41	5.36	4.952		0.41

These results are plotted as curve "B" in Plate XV. It is apparent that the difference in specific heat of the incoming and outgoing gases and the change in volume have a considerable influence on the heating value. Since the products of combustion of a gas containing hydrogen are always going to be less in volume than incoming gases, a small gain is always found when the inlet water is at the same temperature as the room. In commercial work this error is negligible.

3. The Gain or Loss of Latent Heat of the Vapors in the Gases.

The combustible gas as it enters the calorimeter is usually saturated with water vapor and in these tests precaution was taken to saturate it. The air supply may be saturated to various degrees of saturation depending on weather conditions. Tests on the products of combustion

leaving the calorimeter in all cases was only a few degrees higher than the inlet water. Tests of Dr. Immenkötter and Professor Junkers also showed that the products are saturated at the temperature of the inlet water. Now if the products of combustion are cooled far below room temperature the vapor content at the low temperature may be much less than the vapor content of the gases entering the calorimeter. Should the products leave at a temperature higher than the room temperature, and be saturated, a greater amount of vapor is carried away than is brought in and thus the latent heat of condensation is lost from the calorimeter.

The combustible gas enters the calorimeter at 70°F and saturated. 1 cu. ft. dry gas is equivalent to 1.024 cu. ft. gas saturated at 70°F, and hence the vapor brought in per cu. ft. of dry gas at 70°F = 0.024 cu. ft.

The air for combustion was 62% saturated for tests 1 to 12. It required 5.40 cu. ft. dry air to burn 1 cu. ft. saturated gas. The 5.40 cu. ft. dry air are equivalent to 5.48 cu. ft. of air at 70°F and 62% saturated. Hence 0.024 + 0.08 = 0.104 cu. ft. vapor are brought in for every cu. ft. of saturated gas burned. 0.104 cu. ft. at 70° is equivalent to $\frac{.104 \times 490}{530} = 0.0962$ cu. ft. at 32°F. 1 cu. ft. of vapor at 32°F = 0.805 oz. = 22.79 grams.

For every cu. ft. of dry gas burned there is formed by combustion 0.875 cu. ft. vapor at 70°F which is equivalent to 0.813 Cu. ft., or 0.654 oz. at 32°F.

The following computation will show the method employed in all the following cases.

In tests 1 to 4 the exit temperature = 45.9°F and the volume of the dry products of combustion of 1 cu. ft. gas with 14% excess of air = 4.99 cu. ft. The products leave saturated, and the vapor tension at 45.9°F is 0.30 in. mercury, the barometer reading 28.70 inches, and hence the saturated products had a volume of $4.99 \times \frac{28.70}{28.70 - 0.30} =$ 5.05 cu. ft. 5.05 - 4.99 = 0.06 cu. ft. vapor taken out. But 0.0962 cu. ft. are brought in at 32°F, which is equivalent to 0.099 cu. ft. at 45.9°F. The difference, 0.099 - 0.06 = 0.039 cu. ft. vapor added to the calorimeter at 45.9°F, or 7.75°C, which is equivalent to 0.0379 cu. ft. = 0.864 grams at 32°F. The total latent heat in a vapor from 32°F is given as $\frac{.864}{1000} \left(606.5 + (0.305 \times 7.75) \right) 396 = 2.082$ B.T.U in the vapor deposited at 32°F. The temperature of the exit gases in the calorimeter is 45.9°F or 7.75°C, and hence from 2.082 B. T. U. must be subtracted the heat in the condensed vapor from 32°F to 45.9°F. $= \frac{.864}{1000} \times 7.75 \times 3.96 =$ 0.026 B.T.U. The net heat given up to the calorimeter by the vapor condensed out from the incoming gases is 2.082 - 0.026 = 2.056 B. T. U.

In this manner all the other values were computed and they are tabulated below.

TESTS	EXIT TEMP F°	EXIT TEMP C°	HUMIDITY	VOL. VAPOR BROUGHT IN AT 32°F	VOL. VAPOR TAKEN OUT AT 32°F.	GRAMS VAPOR AT 32° LEFT OR REMOVED	B.T.U. OF LATENT HEAT TO 32°F.
1 -4	45.9	7.75	62%	0.0962	0.058	0.864	2.056
5 -8	54.1	12.3	62"	0.0962	0.067	0.669	1.62
9 -12	63.3	17.4	62"	0.0962	0.1036	0.146	0.353
13-16	72.2	22.3	75"	0.1015	0.129	0.63	1.54
17-20	81.5	27.5	88"	0.129	0.182	1.22	2.97
21-24	88.5	31.4	100"	0.138	0.194	4.421	10.8

Table (cont.)

TESTS	B.T.U. IN VAPOR TO EXIT TEMP.	NET B.T.U. LEFT OR TAKEN OUT	REMARKS
1 -4	0.026	2.056	Given to calorimeter
5 -8	0.032	1.59	" " "
9 -12	0.001	0.352	Taken from calorimeter
13 -16	0.06	1.48	" " "
17-20	0.13	2.84	" " "
21-24	0.54	10.26	" " "

The results of these computations are plotted as curve "C" in Plate XV. It is apparent that at the higher temperatures at which the products leave the calorimeter the

loss in heat energy due to the latent heat of condensation increases very rapidly andthe actual amount is large. It is necessary therefore to regulate the damper at the exit for the products of combustion that they leave at a temperature approximating the inlet water.

Now if the curves A, B and C, of Plate XV be combined into one curve the total losses and gains will be given, and such a curve is shown at "D" in Plate XV. The curve "D" when applied to the results shown in curve A in Plate XIV at the corresponding temperatures should give a straight line. There is a slight deviation from this condition due to experimental errors, but if the average of all these points is taken it gives a heating value of 600 B. T. U.

A horizontal line drawn through the ordinate of 600 B.T.U. cuts the curve A of Plate XIV at a point corresponding to a temperature of the inlet water of 72°F. and which is also the point of inflection of the curve. Thus it is plain that if the water supplied to the calorimeter be at room temperature and the products of combustion leave at room temperature there is a thermal balance. The interpretation of the curve having a point of inflection is that at the point of inflection the function changes from a gain to a loss, and it is apparent that the true heating value of

the gas from Plate XIV is 600 B. T. U.

It may happen that the water supply available is not at room temperature, and thus an error would be made in determining the heating value. It would be convenient if a simple correction could be applied, or if the equation of the curve A on Plate XIV could be obtained. This curve has the form of a cubical parabola whose general equation is $-y = \frac{x^3}{a^2}$ where (y) = the ordinate, (x) the abscissa, and (a) the parameter. By a proper choice of a value for (a) the curve can be made to assume a variety of shapes. If the origin of the curve be at the point where the ordinate for B.T.U. rises from the point of the temperature of the inlet water corresponding to room temperature, and if X = F° difference between room temperature and inlet water, then (y) would give the B. T. U. to be added to or subtracted from the value found. For the curve A, Plate XIV which represents fairly average conditions the value of (a) = 17.75.

Suppose that a test for heating value is made with the room at 70°F, the inlet water at 60°F. Then $x = -10°$, $a^2 = 315$, and $+y = \frac{+1000}{315} = +3.16$ B.T.U. which must be subtracted. If the inlet water were at 80°F, then $x = +10°$ and $-y = \frac{1000}{315} = 3.16$ B.T.U., which means that 3.16 B.T.U. must be added to the value found.

The equation $-y = \frac{x^3}{315}$ fits the curve A, Plate XIV

exactly above the room temperature, but does not fit well at more than about 12°F below room temperature, and thus there is a limitation. A correction factor at best is undesirable, and it would be preferable if the air, gas, products of combustion and water used in the test were all at the same temperature.

The above equation holds, of course, only for a room temperature of 70°F. If the room temperature is much lower the curve will be straighter than at 70° and should the room temperature be much higher the curve will have about the same shape but will bend down faster at temperatures above the room temperature. In a general way the curve will change its direction in approximately the same degree as vapor tension curves do.

The Effect of Humidity on Heating Value.

It is apparent from curve "C", Plate XV that the heat losses and gains due to difference of humidity between the gas and air supplied and the products of combustion have some effect on the heating value. The data at only a small range of humidity are shown in the above curve, and hence a series of tests were made on Junkers ccalorimeter #872. The gas used for combustion was admitted in a saturated condition and the air supply was changed to give percentages of humidity ranging from 40% to 70%. The water supply was kept constant at approximately room temperature and

all tests made in the regular manner. The results are shown in Table 14 and Plate XVI (Series AA). Reference to Plate XVI shows that with the same sample of gas at 70°F and a change of humidity of 30% there is only a variation of 3.0 B.T.U. This result seemed rather small and an additional test was applied.

A series of computations were made similar to those which were made to give the results shown in curve "C", Plate XV. In the present computation it was assumed that the products of combustion left the calorimeter at room temperature. Three sets of data for curves were computed on the basis that the room temperatures were at 60°, 70° and 80°F and at each temperature the humidity varied from dry air to 100% saturation. The gas supply in all cases was assumed saturated. The data used to produce the curves on Plate XV served as a basis for computation, making the proper allowances for the temperatures of the room assumed here.

The heat in B.T.U. gained or lost by the calorimeter at 60°, 70° and 80°F with a humidity of 0.0%, 25%, 50%, 75% and 100%, at each of these temperatures is plotted in curves and shown in Plate XVII. For a temperature of 70°F the B. T. U. lost by the calorimeter between the points of 40% and 70% humidity is 3.16 B.T.U. This value checks the experimental determination of 3.0 B.T.U. very closely, and

the effect of humidity within the ranges commonly met in practice is not very large.

Since a range of room temperature from 60° to 80°F represents an average range at which a calorimeter is operated, a degree of saturation of the air supply of about 80% would nearly eliminate any errors. In general, the humidity of the room in which the calorimeter is operated should be between 70% and 80% for good results.

CHAPTER VII.

Conclusions.

Since the purpose of this investigation was to obtain some information on the relative merits of gas calorimeters and the methods of operation, the conclusions that can be based on the tests made fall naturally in two parts:-- the type of calorimeter outfit which will give correct results, and the general method of operating the same. None of the calorimeter outfits were satisfactory in all respects, and most of them had very desirable features. The following specifications for a calorimeter outfit and directions for operation of the same are the conclusions resulting from this investigation.

(1). Calorimeter Body.

The calorimeter body should be designed to give a perfect exchange of heat from the combustion to the water. The outside should be of bright polished metal and an air jacket should protect the instrument from radiation and absorption losses. Absorbent jackets should be carefully avoided. The body should be mounted on legs to give a good firm base and high enough to admit the burner into and out of the combustion chamber with ease. A damper in the exhaust gas flue should be provided which may be easily and definitely regulated.

A constant head of water should be maintained on

the body. This can be attained by having a weir overflow on the inlet at some distance above the calorimeter, and a weir overflow at the outlet. The rate of flow through the calorimeter can be regulated by a cock at the inlet which can be adjusted easily to give small or large changes.

The water should circulate freely so that there is an equal distribution of water through the calorimeter. Baffle plates should be so arranged that the water is mixed thoroughly before coming in contact with the bulb of the thermometer at the outlet. The design should avoid the formation of air pockets in the water space. Errors were frequently found in tests due to this defect in the instrument.

It is highly desirable that the thermometers for indicating the temperatures of the inlet and outlet water be on the same level and near together, and the openings for the stoppers holding the thermometers should be at least 3/4 inch in diameter. The water should bathe the thermometer bulb freely and sufficient space should be provided for the passage of the water past the thermometer into the inlet and outlet.

(2). Burners.

A bunsen burner proved most satisfactory in all tests. There should be a device on the air mixing chamber

of the burner by which the air supply can be adjusted while the burner is in position in the calorimeter. The burner should be provided with a cock to regulate the gas supply. The burner should be attached to the calorimeter in such a manner that its position cannot be accidentally shifted when once in position, and also so that the condition of the flame can be readily observed by the operator, either directly or by means of a mirror.

(3). Meters.

Meters registering to 1/10 cubic foot per revolution were found most satisfactory. The large dial should be graduated into 100 equal parts with every ten divisions plainly marked. In addition to the large dial there should be smaller dials which register the number of revolutions of the large hand. These dials should register 10ths, units and 10's of cubic feet.

The face of the meter should be enameled and no glass used on the front. The face of the meter should be easily removable to get at the shaft and its stuffing box which ought to be large enough to permit efficient packing.

The large hand of the meter should be well pointed and not extend beyond the graduations on the dial. Meters with wide pointers gave trouble for accurate calibration.

Three leveling screws instead of four should be

supplied with the meter, two in front and one behind. To facilitate the leveling of the meter, two level tubes should be securely fastened on the meter at right angles to each other.

On the outside of the meter there should be a gauge glass which is not less than 3/8 inch and not more than 3/4 inch internal diameter. The glass needs to be large enough to permit easy cleaning and small enough to form a definite meniscus. The opening from the gauge to the meter should be approximately the same size as the glass. A pointer marking the correct level of water in the gauge glass as shown by the bottom of the meniscus should be attached.

An opening should be provided on the meter for the addition of water when needed. This opening should be provided with a petcock and funnel connected to the top of the gauge glass. A drain device should also be provided on the bottom of the meter when it needs to be emptied.

Near the gas outlet of the meter a provision should be made for a thermometer. This thermometer should be a good chemical thermometer in a metal case and should have a range from 50 to 100°F and graduated to 1°F,and be accurate to 1/2°F.

The number of joints liable to leakage on the me-

ter should be reduced to a minimum. A great source of trouble on many meters was the breakage from faced joints.

(4). Pressure Regulator.

A wet pressure regulator is the most satisfactory instrument. Since it is necessary to keep the pressure absolutely uniform to get correct results, the regulator should be so designed that the pressure can be regulated with ease and certainty.

(5). Water Measurement and Supply.

The quantity of water used for a test can be either weighed or measured. Suitable containers can be readily obtained. A scale having a capacity of 10 pounds and sensitive to 1/100 pounds is a satisfactory means of getting the weight of water. A suitable measuring device that has a small enough meniscus is also satisfactory if the determination can be made within 1/100 pounds. For a portable outfit, a measuring device is perhaps the most convenient.

It is very necessary that the water supply be of constant temperature. The supply when taken direct from city service mains is rarely at a constant temperature. An overhead tank in the room where the calorimeter tests are made is an efficient device. This tank should have a sufficient capacity to run the calorimeter for about 25 minutes. The water used for the tests can be pumped back into the tank and used over again. In this manner a constant pressure and

temperature of the water supply is assured.

(6). Thermometers.

Accurate thermometers are absolutely necessary for accurate work on calorimeters. The thermometers supplied with the instruments tested had inaccuracies of bore that introduced errors amounting to as much as 10 B.T.U.

The thermometers should have a range of from 65°F to 120°F and graduated to 1/10°F. Each thermometer should be supplied with proper calibration curves. The thermometers should not be more than 3/8 inch in diameter and be made of thin glass if of the enclosed milk glass type. Greater dimensions of diameters on both types of thermometers introduce errors due to paradox.

Telescopic sights should be used when making observations, because the eye is then always in the same relative position, and more accurate readings are possible.

(7). Gas Piping and Tubing.

Whenever possible metallic piping should be used. The heavy hydrocarbons are absorbed by the rubber and make it brittle and liable to leak. The effect of the removal of these hydrocarbons while passing through a short length of rubber will not reduce the heating value appreciably.

(8). Humidity.

The determination of humidity is of minor import-

ance as there is only a small change in heating value with a relatively large variation of humidity. The average humidity should be about 75%. A wet and dry bulb thermometer where a current of air impinges on the wet bulb, or a sling psychrometer are satisfactory instruments for determining humidity.

(9). Method of Operation.

Set the calorimeter up in a quiet room free from draughts and whose temperature can be kept constant. Draughts influence the air supply and hence the amount of heat given to the calorimeter. The room temperature should not be under 60°F and not much over 80°F.

Arrange the calorimeter and its accessories with reference to the gas and water supply that both can be reached readily from the position taken in operating the calorimeter. When the gas connections have been made allow sufficient gas to pass the burner so that the meter makes several revolutions. Shut the gas off at the burner and observe whether the pointer of the meter moves. All leaks must be carefully avoided.

If the meter and pressure regulator have been filled with fresh water, allow gas to pass for about an hour, to saturate the water with the gas. Adjust the level of the water in the meter which has been carefully leveled

to the height shown by the pointer on the outside of the gauge glass.

If new rubber tubing is used, gas should be passed through it for about two hours to saturate the tubing thoroughly with hydrocarbon vapors.

Admit water to the calorimeter and it is best to let the water flow at its maximum capacity in order to insure the expulsion of all air in the water chamber. All of the calorimeters tested had a tendency to entrap some air and the admission of the full water supply prevented the air from remaining. Remove the stoppers at inlet and outlet through which the thermometers are inserted to insure the expulsion of any air under the stoppers.

After water has been admitted to the calorimeter the burner is lighted and the gas consumption regulated by means of the cock on the burner to that rate which experiment has shown will give the maximum efficiency. Then adjust the air supply to the mixing chamber in the burner so that the flame has a faint luminous tip.

The lighted burner is then placed in position in the calorimeter and the water supply adjusted by means of the regulating valve at the water inlet so that the rise of temperature at the outlet is about 10° to 15°F. The gas is allowed to burn in the calorimeter for about 20 minutes be-

fore any test is made. This is necessary to insure that the calorimeter has reached a constant condition. Condensed water should be dripping freely from the calorimeter before the test is made. Observe whether the water supply is at a constant temperature and also whether the temperature of the water at the outlet is steady. Adjust the damper on the exhaust gas flue so that the temperature of the escaping products is approximately that of the room.

Just before beginning the test observe the barometer, temperatures of the gas, the room and the exhaust products. Then as the pointer of the meter passes the zero point on the dial, shift the water from the drain to the measuring device. Begin the observation of the temperatures of the water at the inlet and outlet, making as many observations as possible. At least ten observations should be made. Just as the pointer of the meter passes the zero mark the second time, indicating 2/10 cubic foot, the water is shifted from the measuring device to the drain.

To get the uncorrected heating value, multiply the weight of water used during the test by the difference between the corrected averages of the inlet and outlet temperatures and divide the product by 0.2, and the result is B.T.U. divided by the proper correction factor gives the correct heating value under standard conditions.

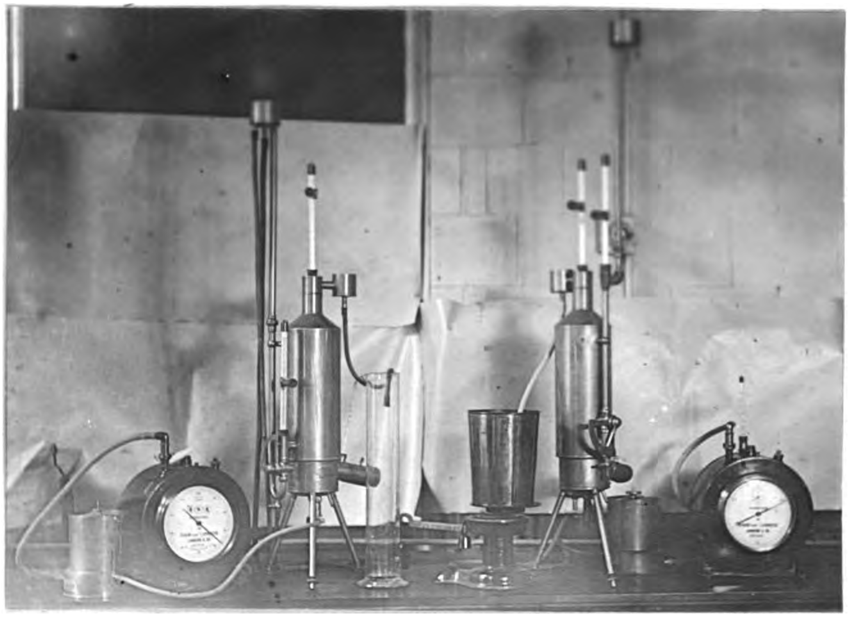

Fig. I. View of Junkers

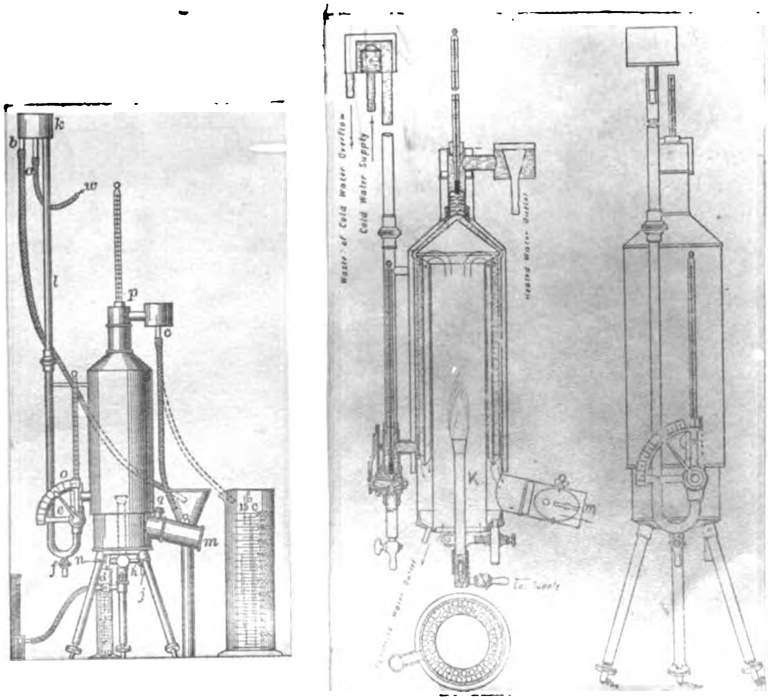

Fig. II. Section of Junkers

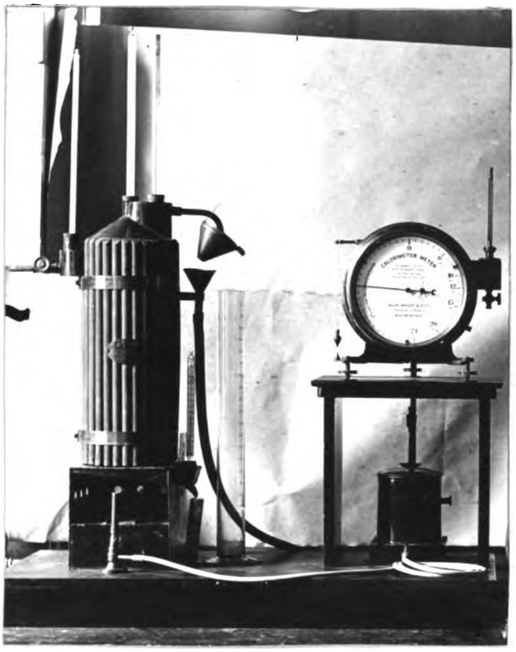

Fig. III. View of Simmance-Abady.

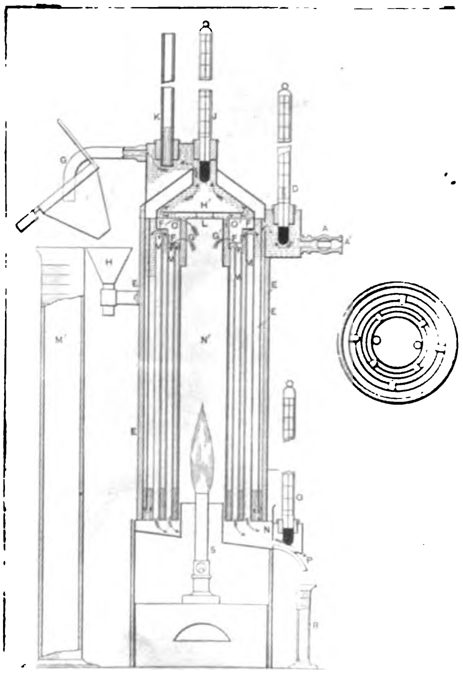

Fig. IV. Section of Simmance-Abady.

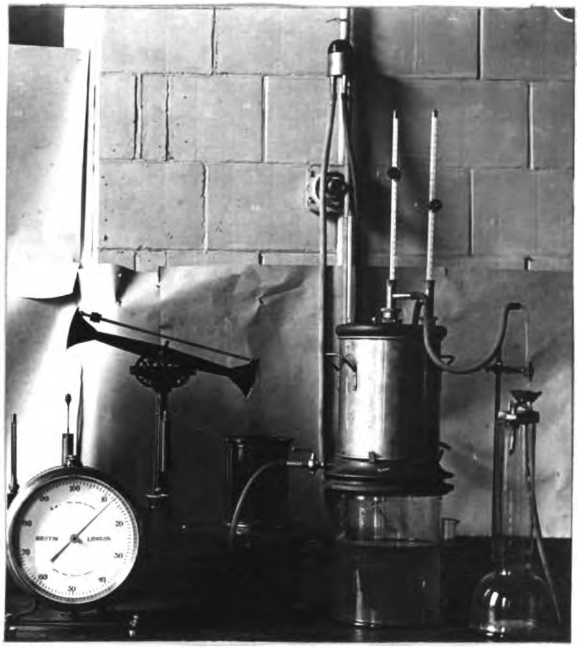

Fig. V. View of Boys.

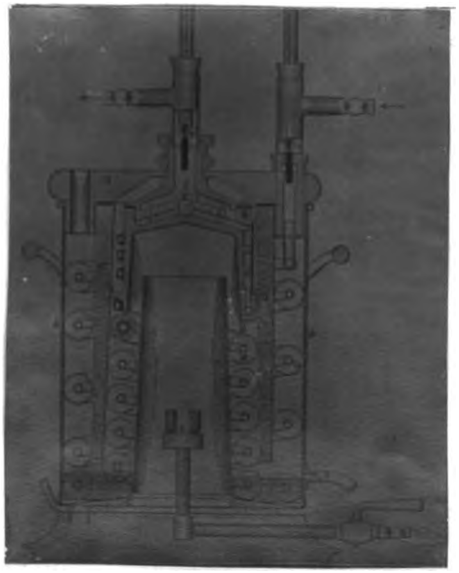

Fig. VI. Section of Boys

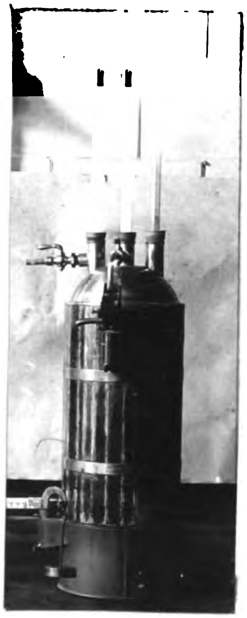

Fig. VII. View First Model of Sargent.

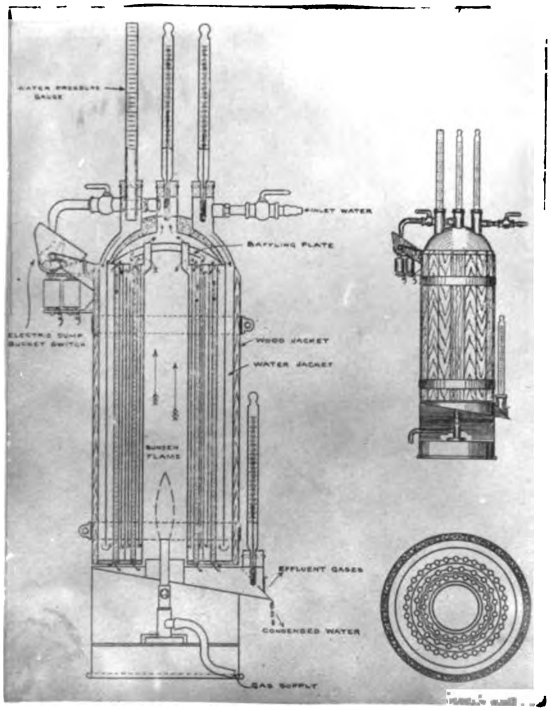

Fig VIII. Section of First Model Sargent.

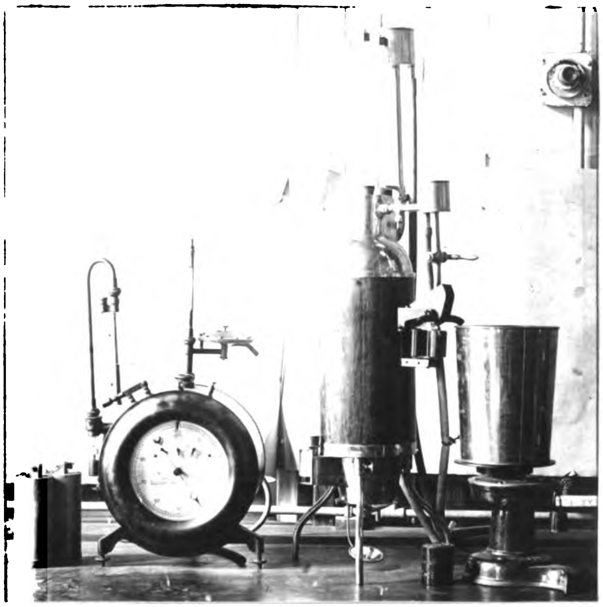

Fig. IX. View of Second Sargent Model.

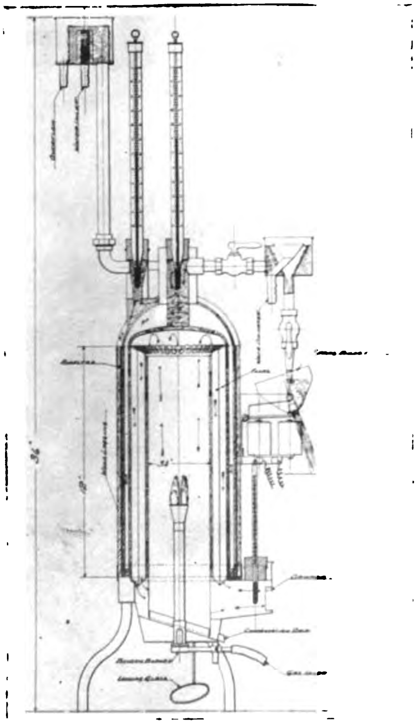

Fig. X. Section of Second Sargent Model.

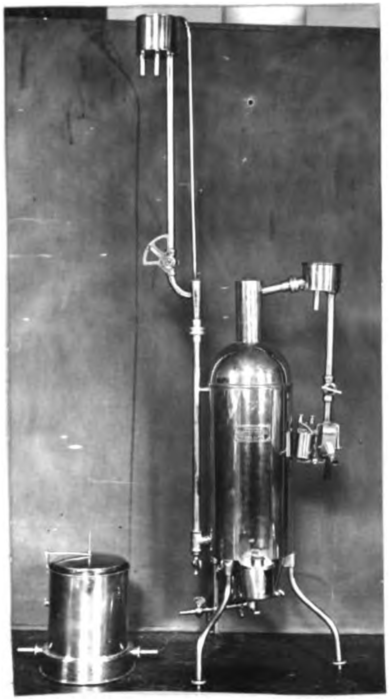

Fig. XI. View of 1909 or Third Sargent Model.

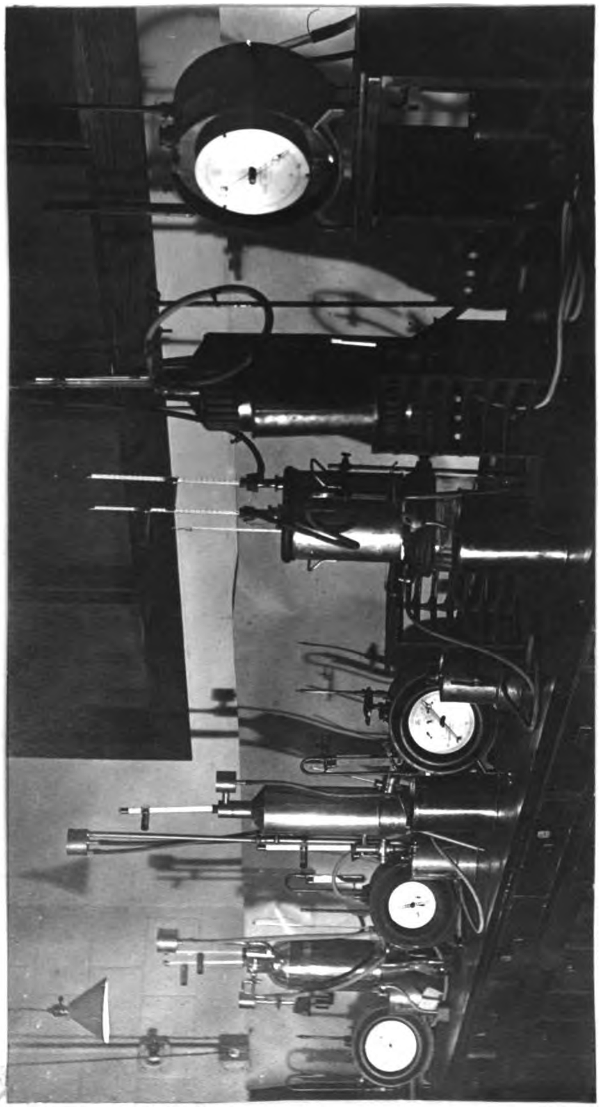

Fig. XII. View Showing Calorimeters Under Test.

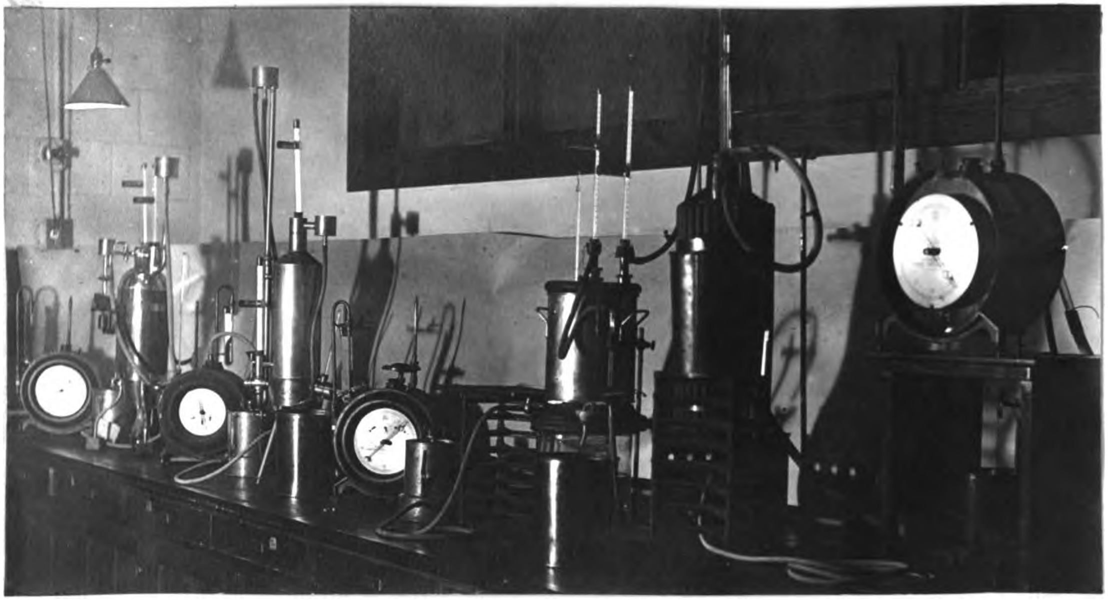

Fig. XII. View Showing Calorimeters Under Test.

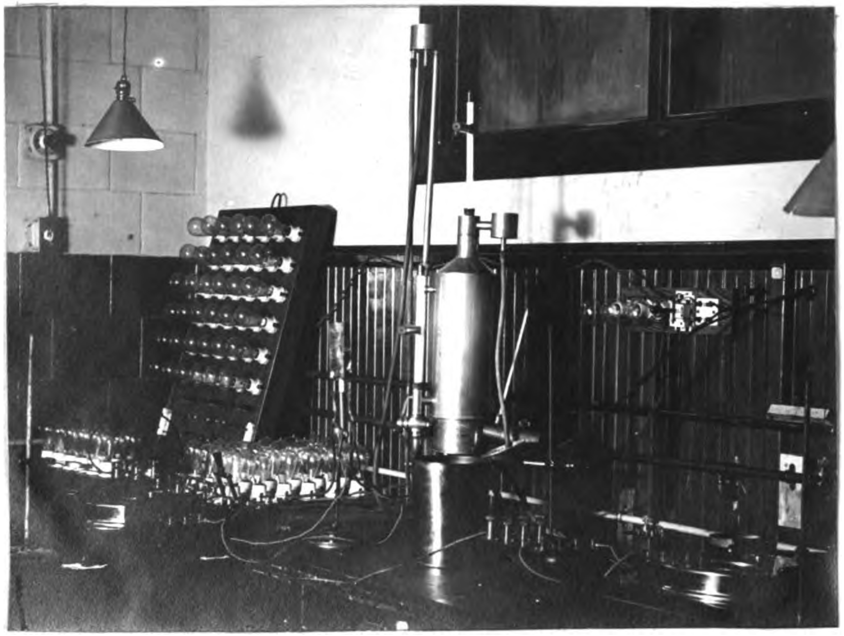

Fig. XIV. View of Apparatus far
Electric Efficiency Test.

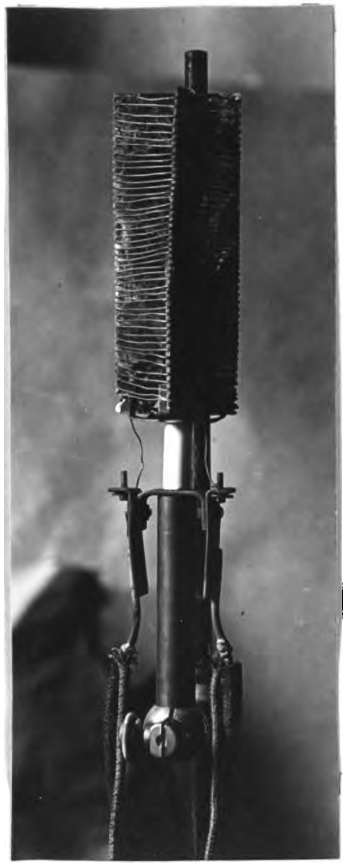

Fig XIII. Heating Coil.

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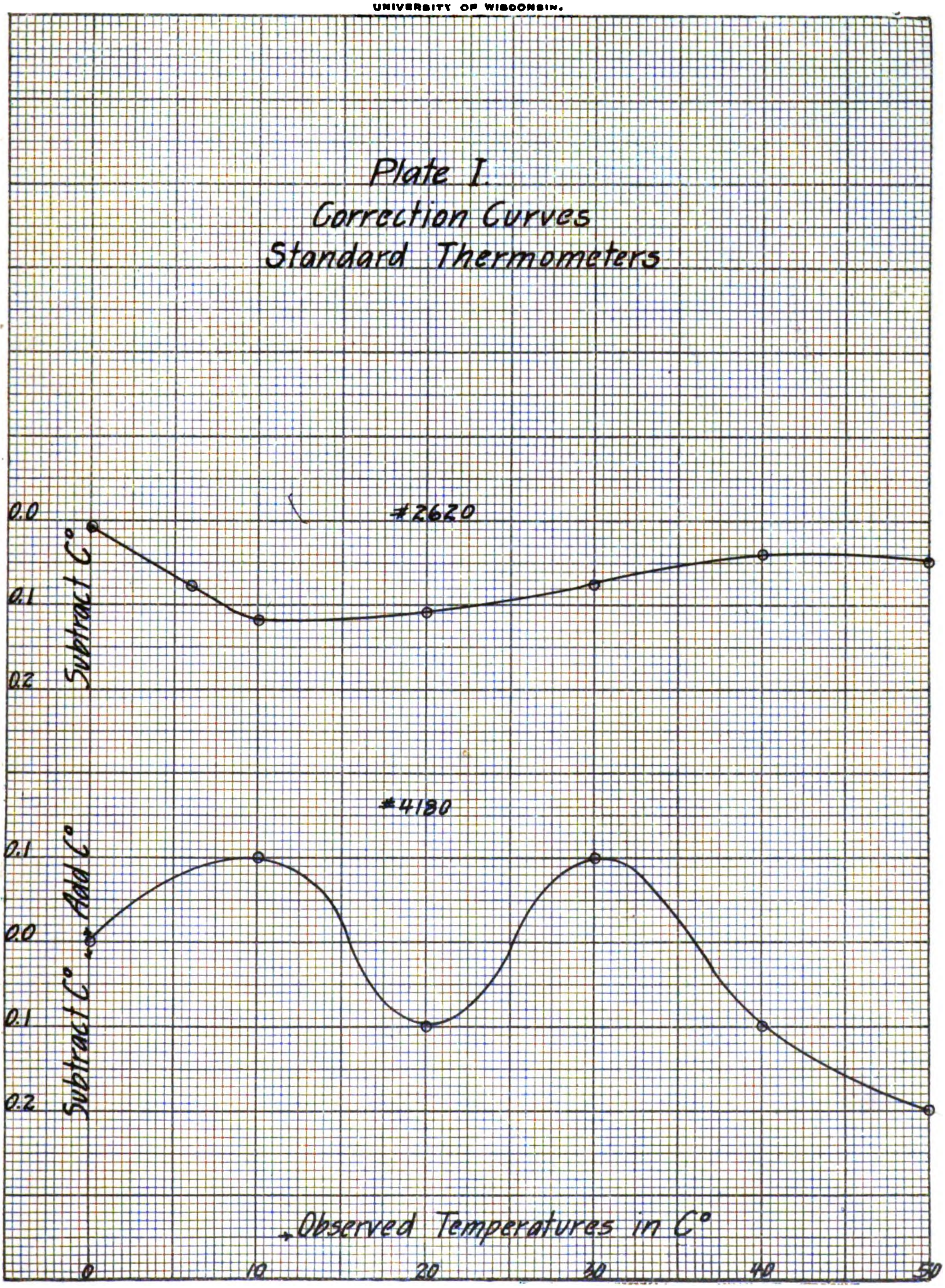

Plate I.
Correction Curves
Standard Thermometers

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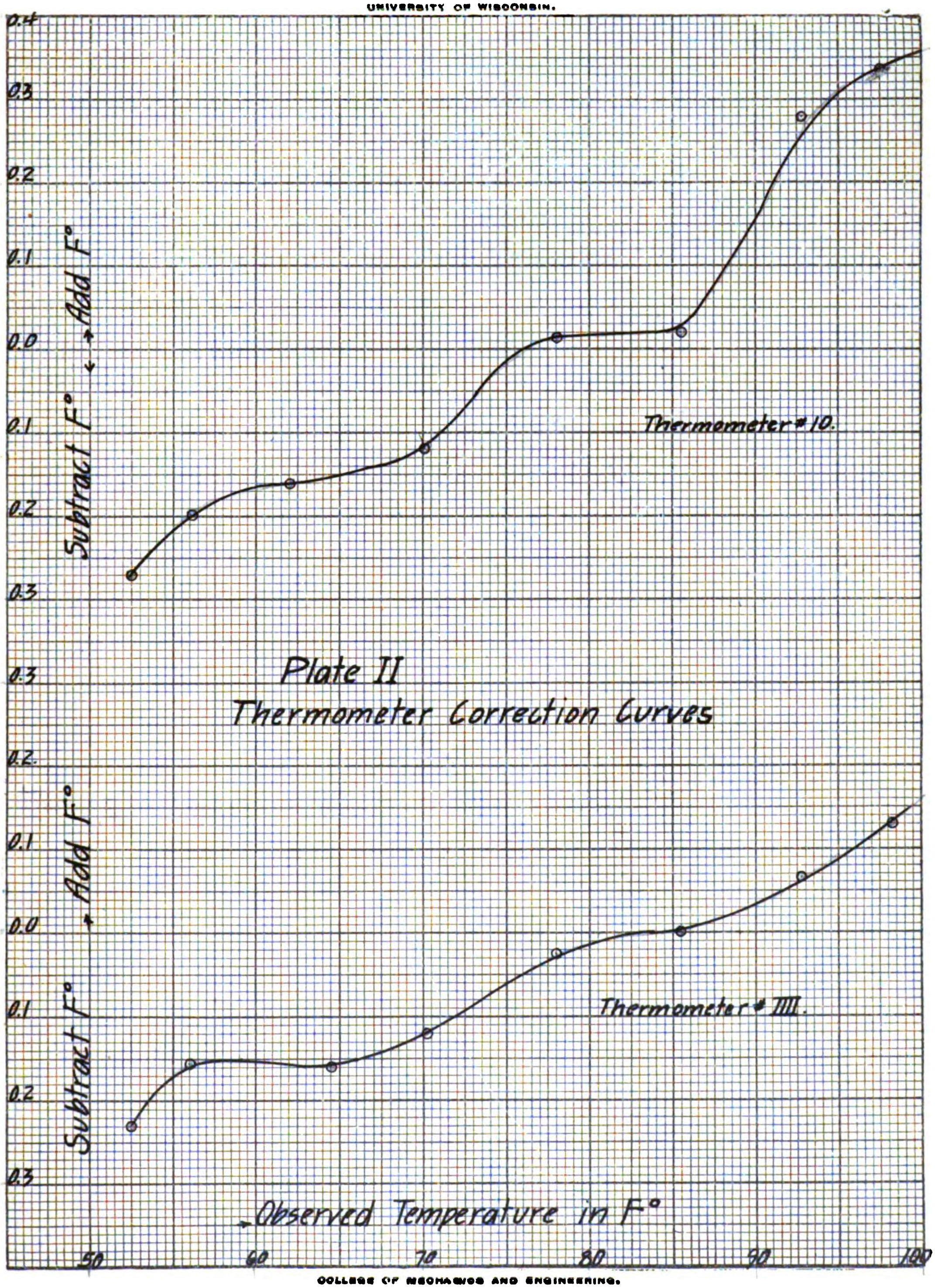

Plate II
Thermometer Correction Curves

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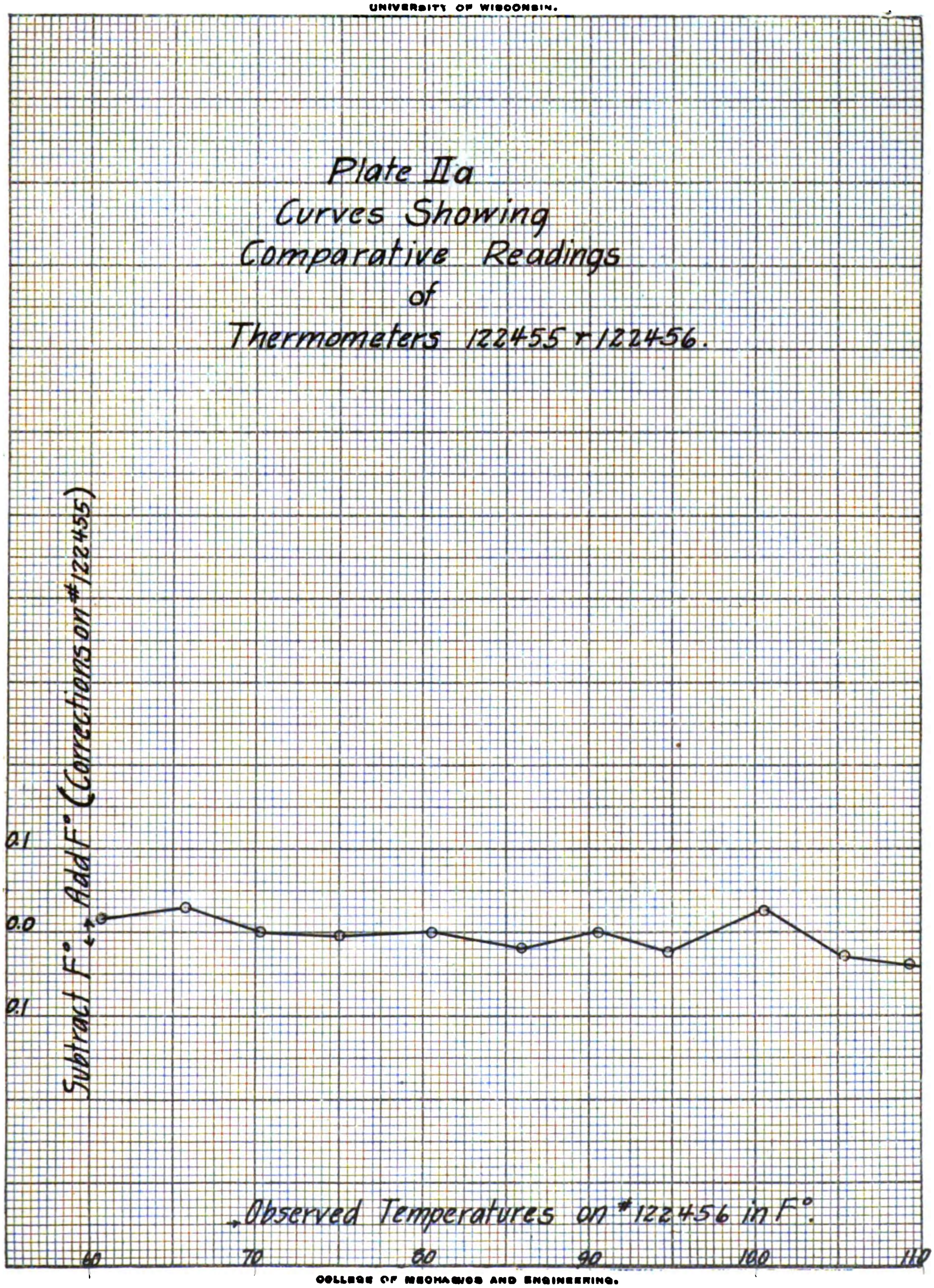

Plate IIa
Curves Showing
Comparative Readings
of
Thermometers 122455 & 122456.

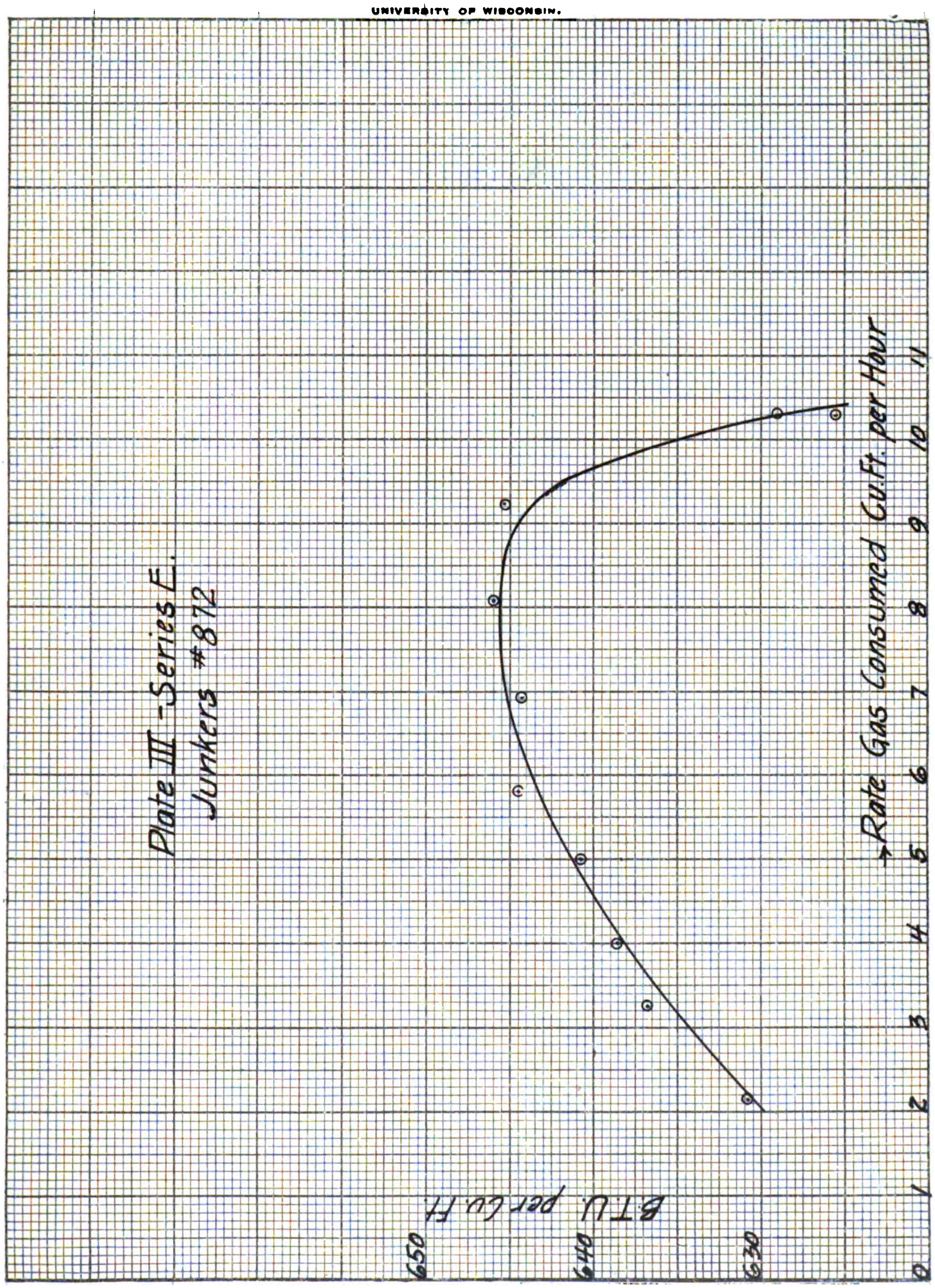

Plate III - Series E.
Junkers #872

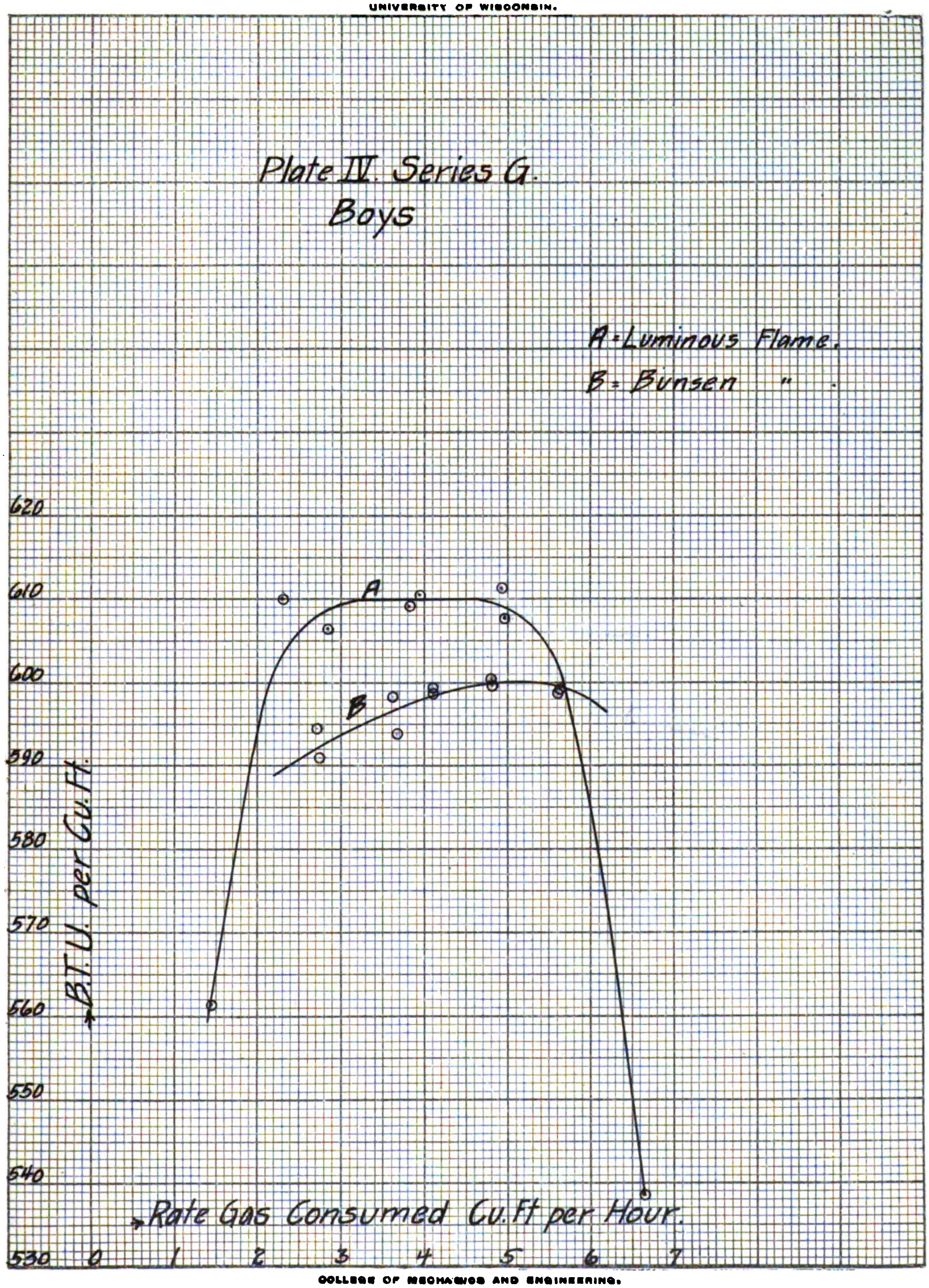

Plate IV. Series G.
Boys

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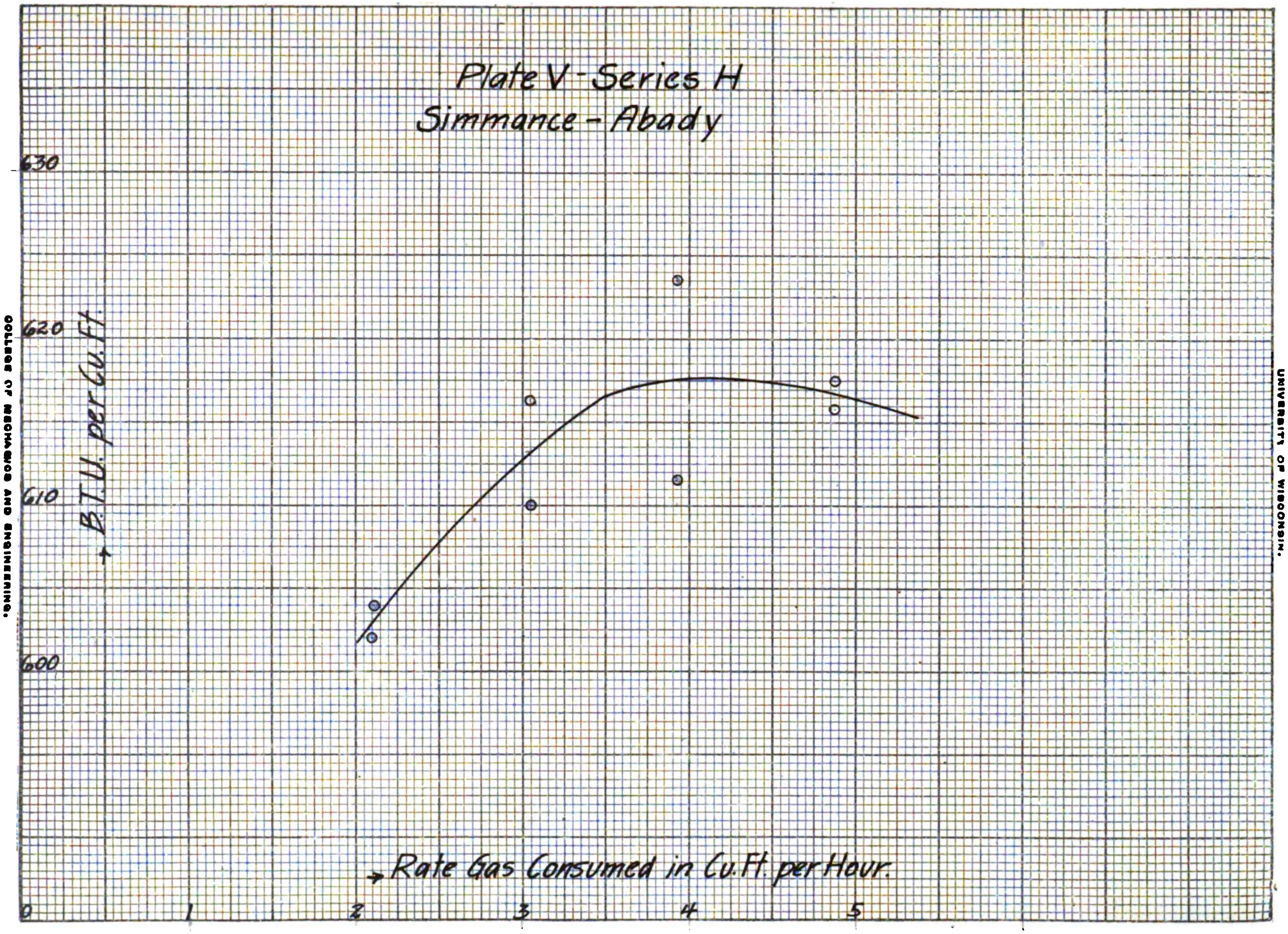

Plate V - Series H
Simmance - Abady

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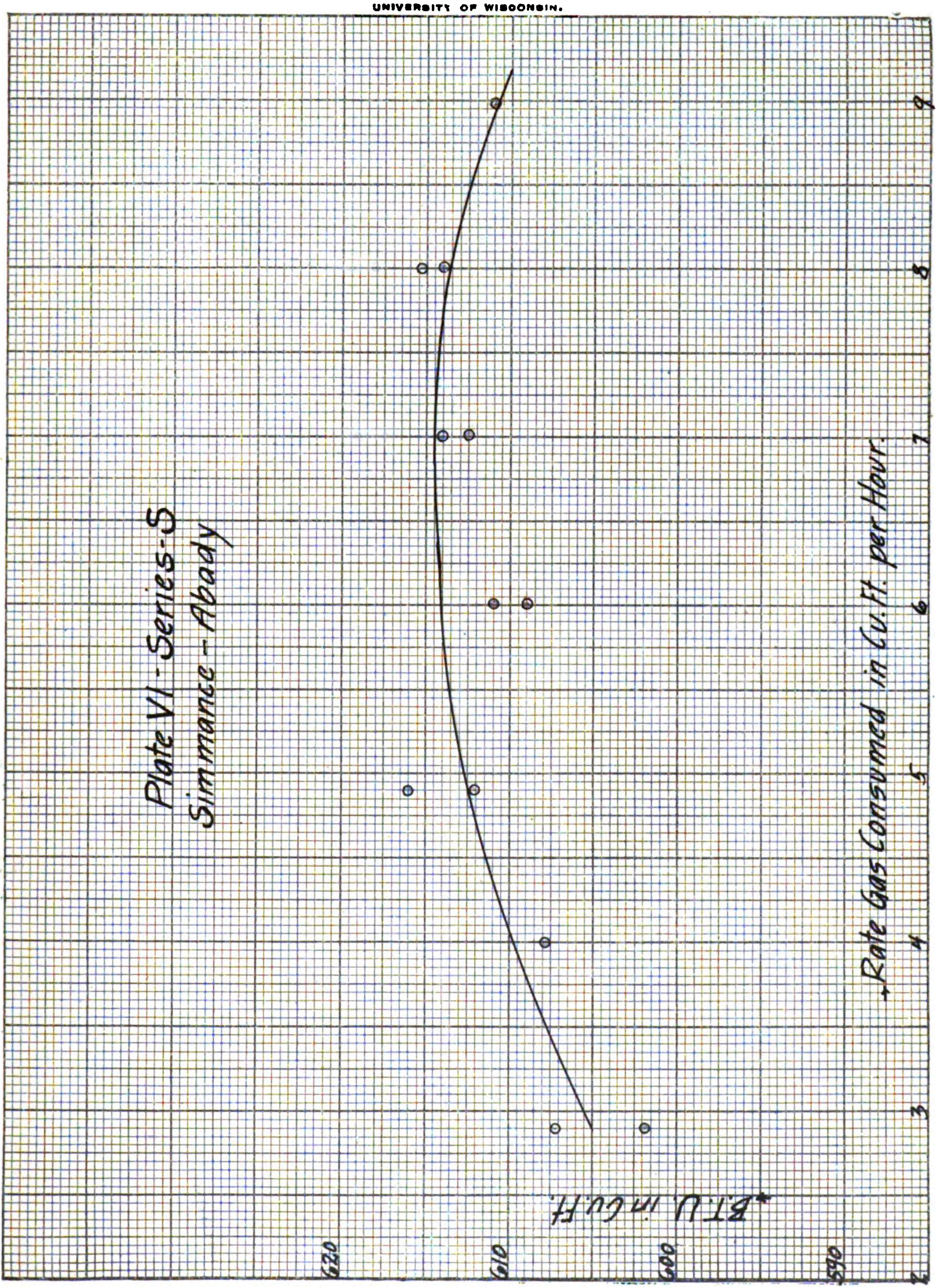

Plate VI - Series-S

Simmance - Abady

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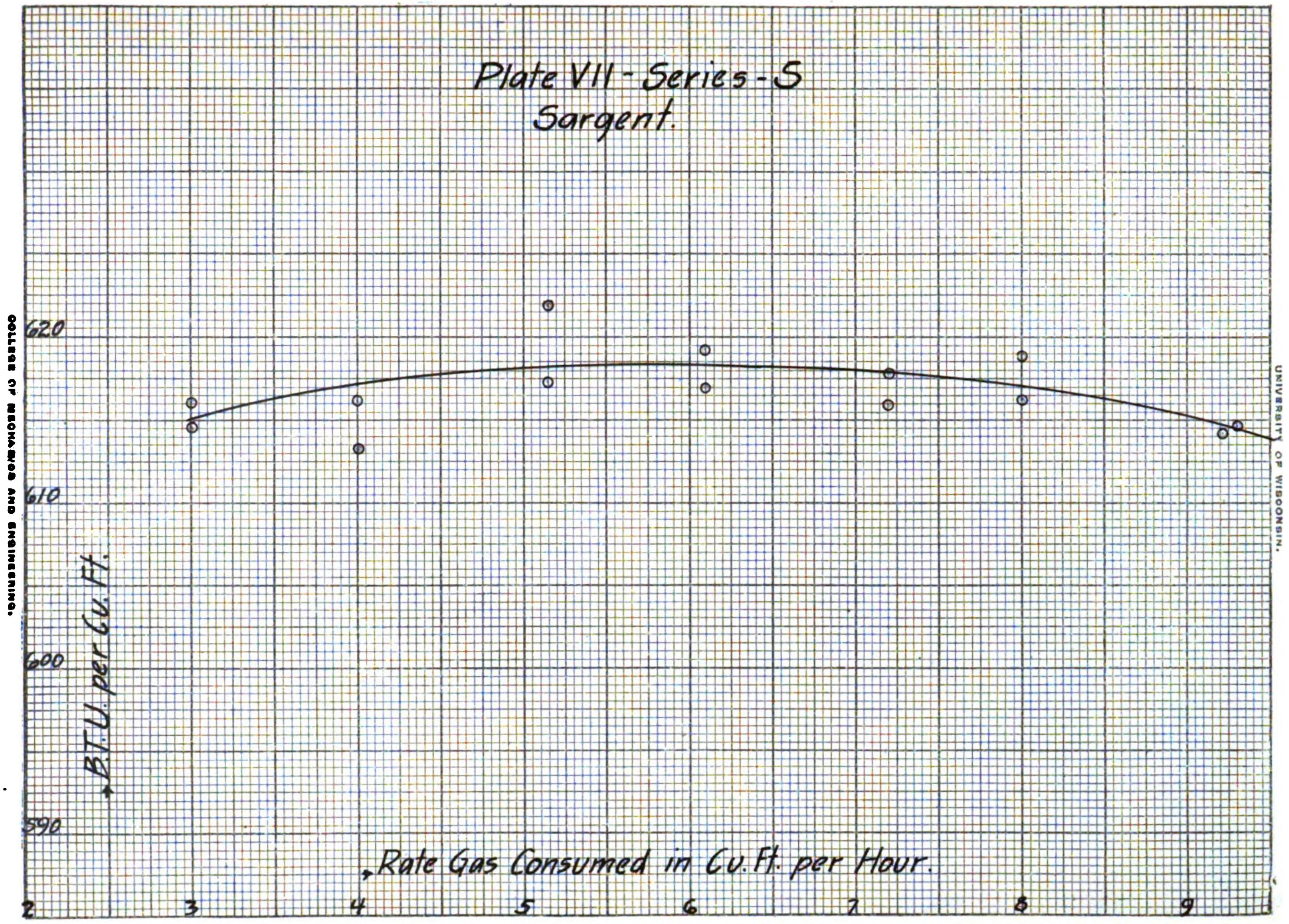
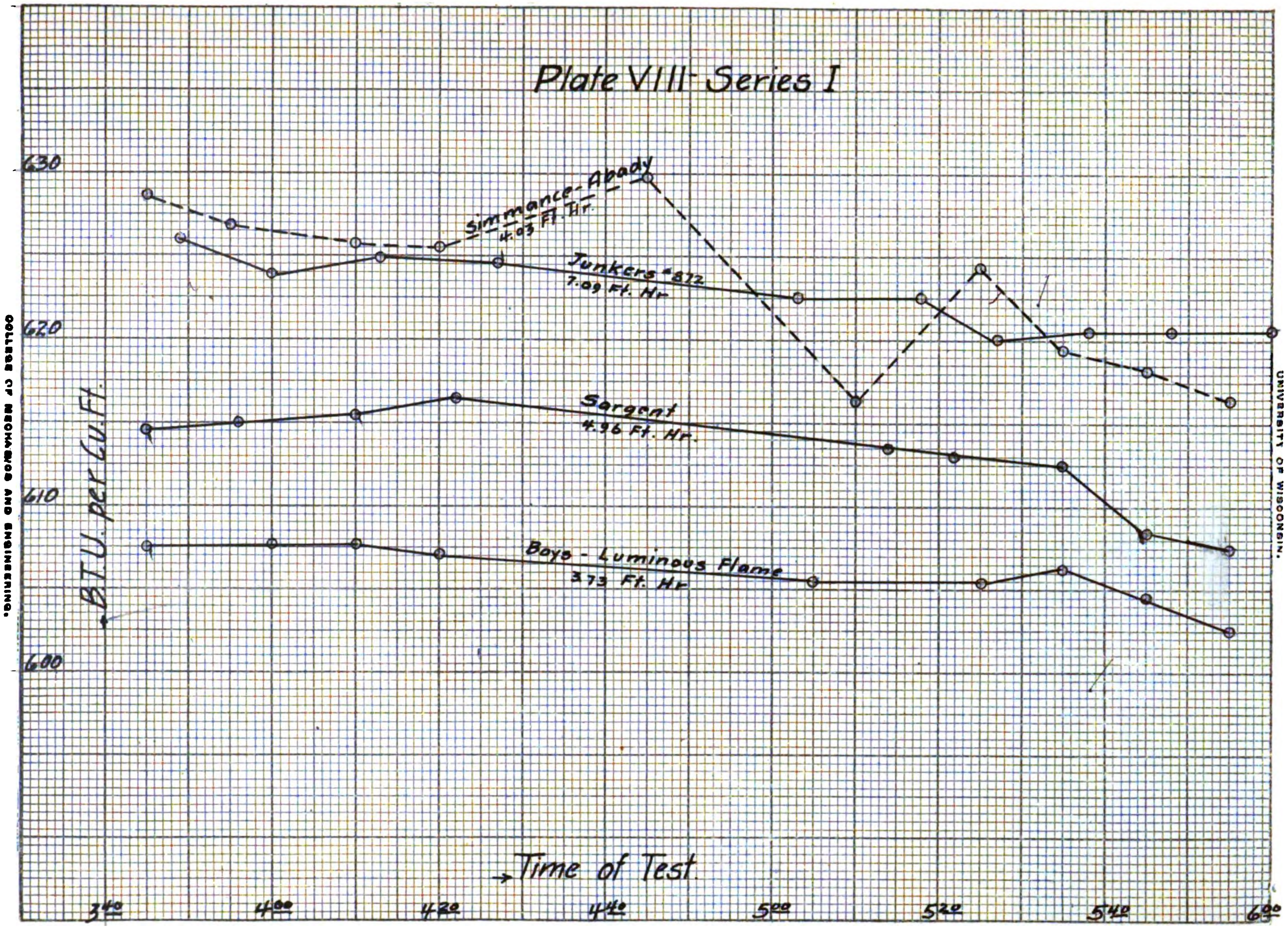
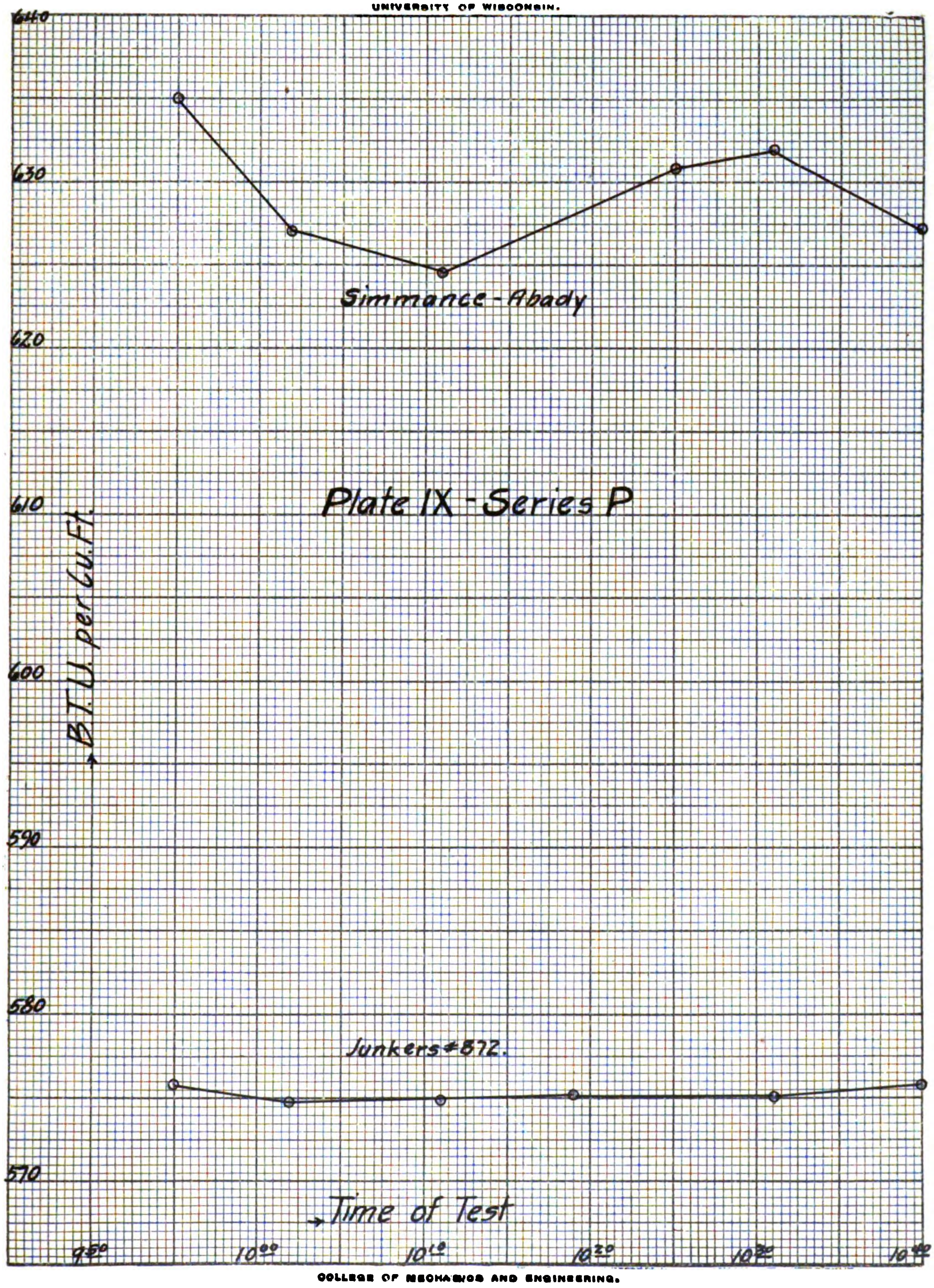


Plate VII - Series - S
Sargent.


UNIVERSITY OF WISCONSIN.
Plate VIII Series I
Simmance-Abady
4.03 Ft. Hr.
Junkers #872
7.09 Ft. Hr
Sargent
4.96 Ft. Hr.
Boys - Luminous Flame
3.73 Ft. Hr
B.T.U. per Cu. Ft.
630
620
610
600
Time of Test
3⁴⁰
4⁰⁰
4²⁰
4⁴⁰
5⁰⁰
5²⁰
5⁴⁰
6⁰⁰
COLLEGE OF MECHANICS AND ENGINEERING.


UNIVERSITY OF WISCONSIN.
640
630
620
610
600
590
580
570
Simmance - Abady
Plate IX - Series P
B.T.U. per Cu. Ft.
Junkers #872.
Time of Test
9^{50}
10^{00}
10^{10}
10^{20}
10^{30}
10^{40}
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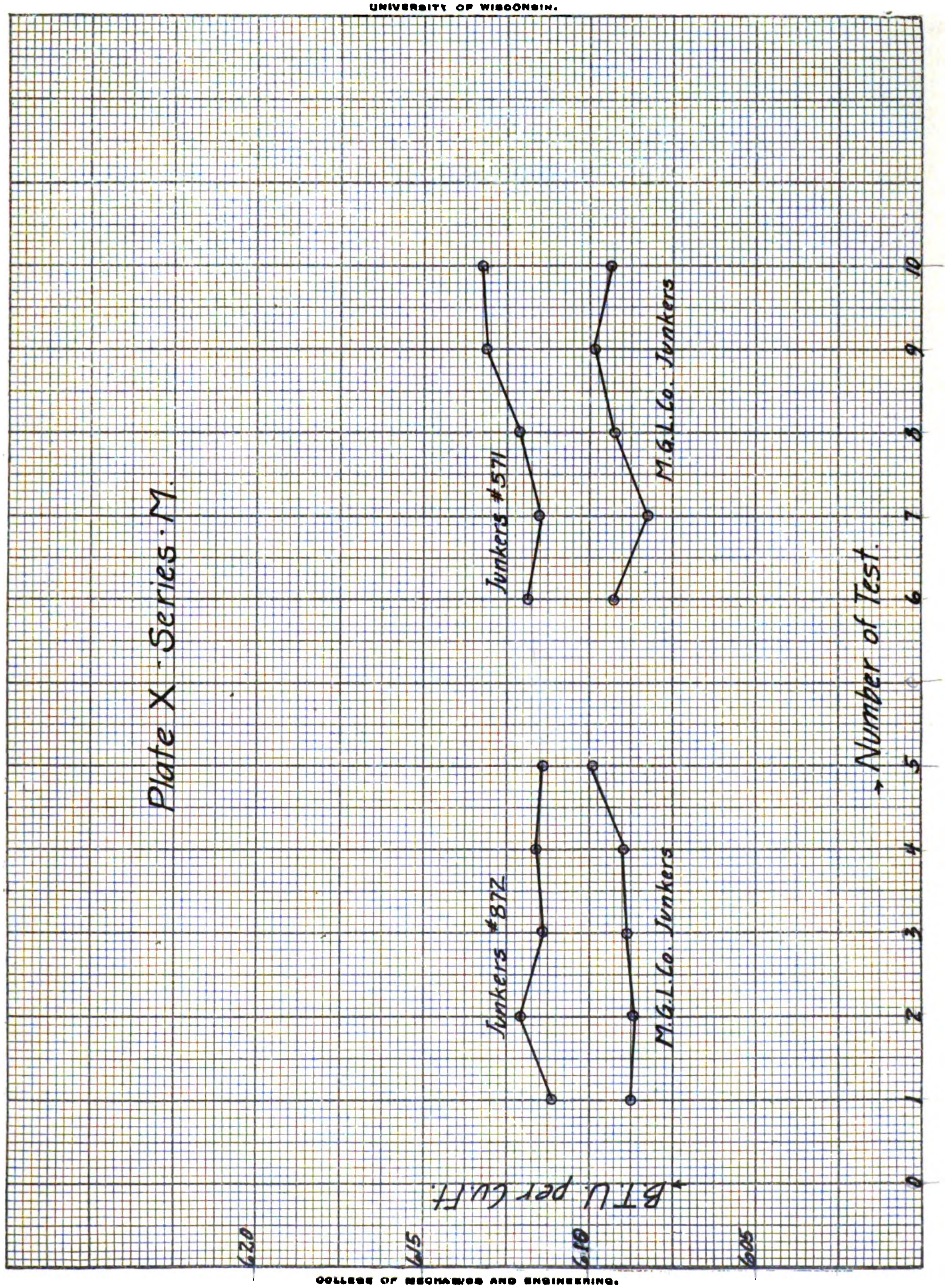

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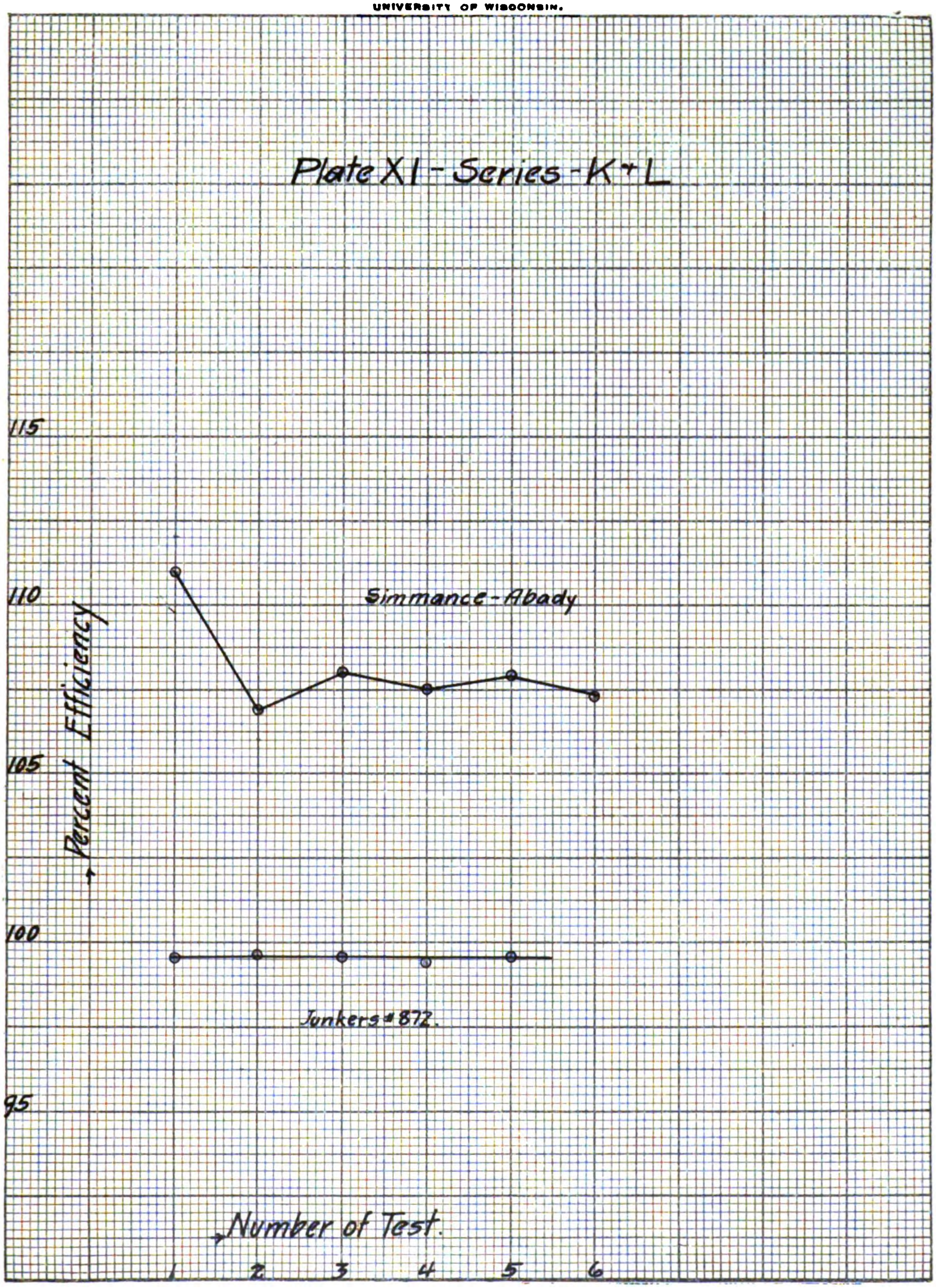

Plate XI - Series - K + L

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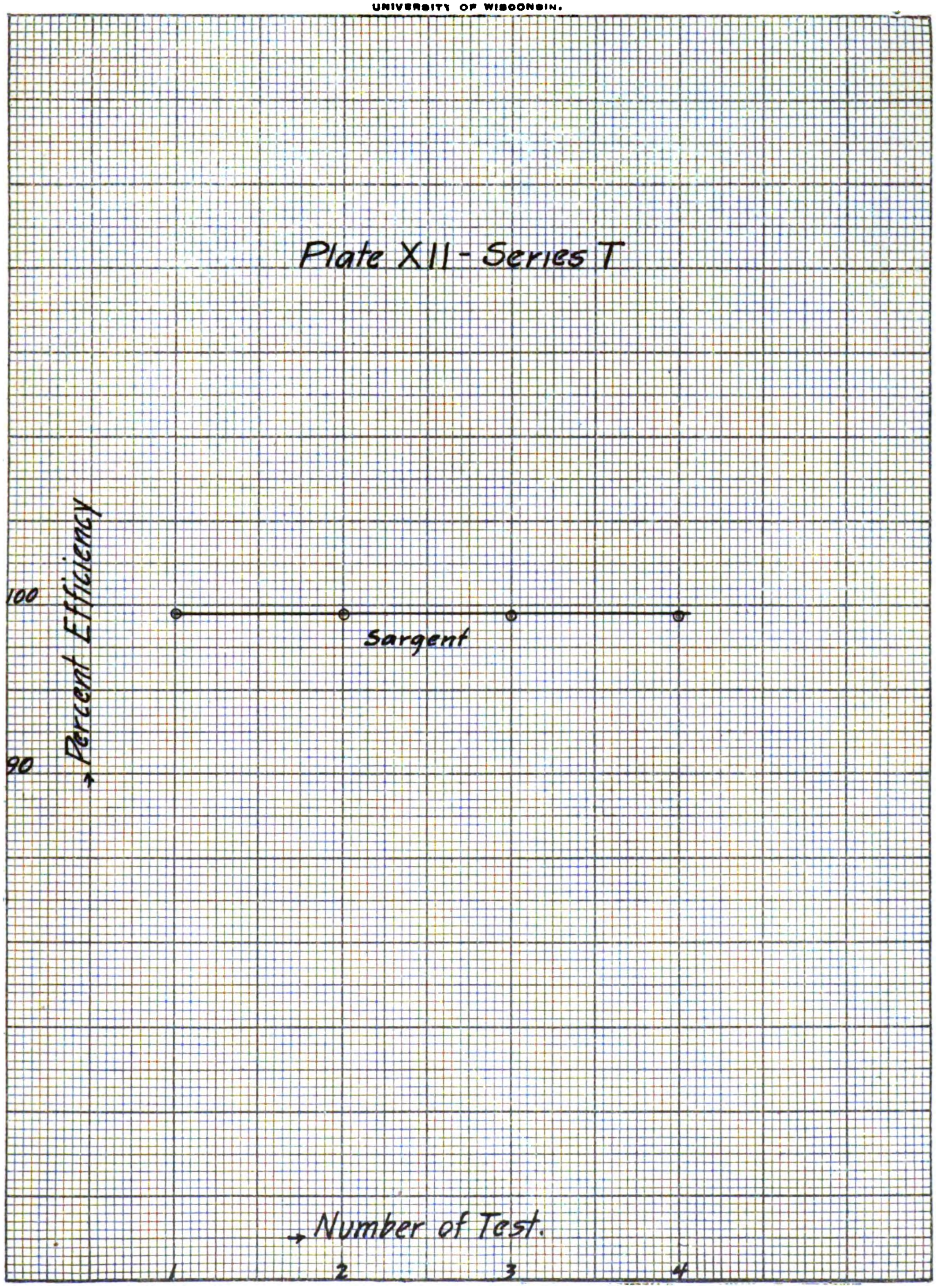

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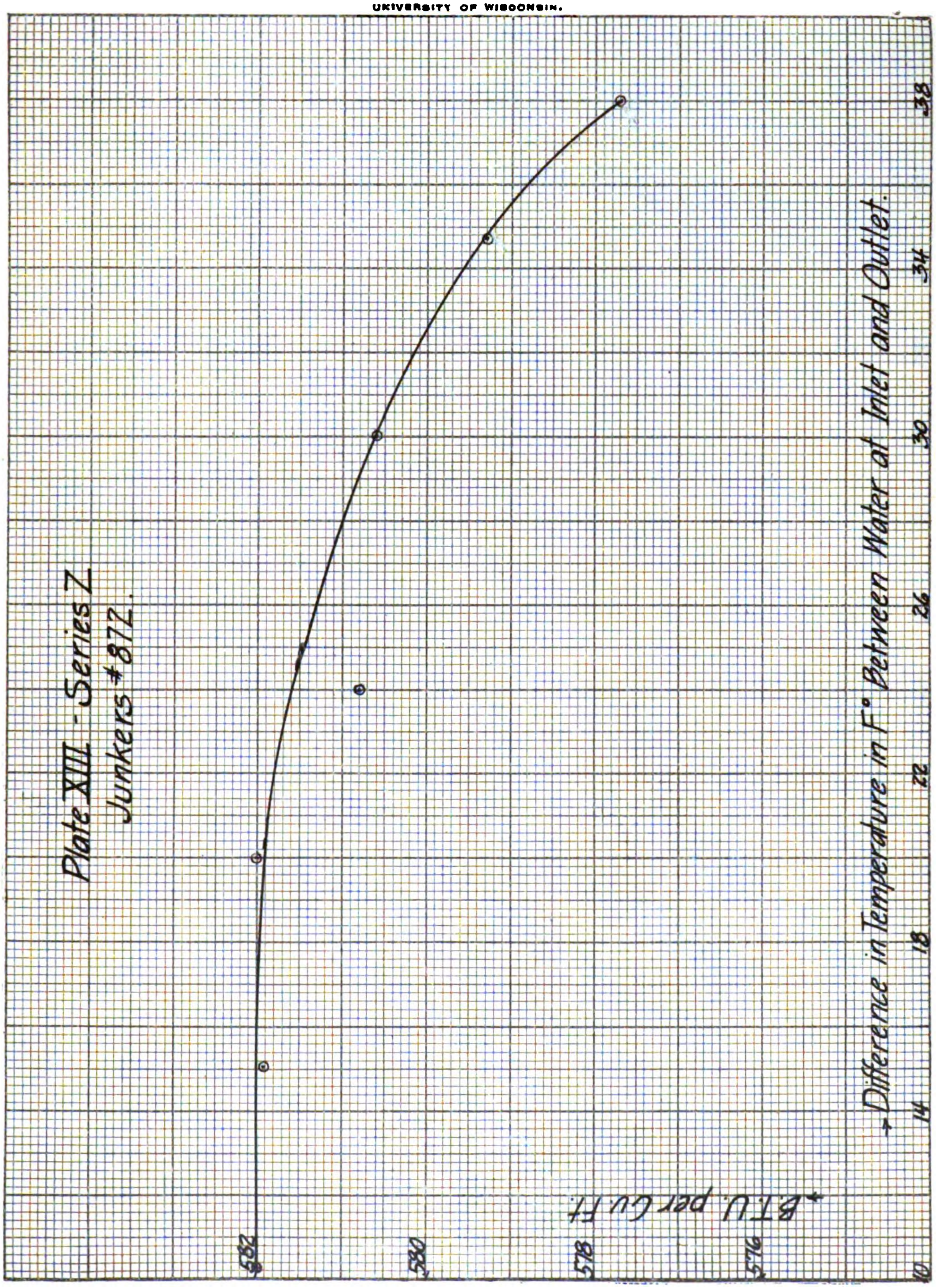
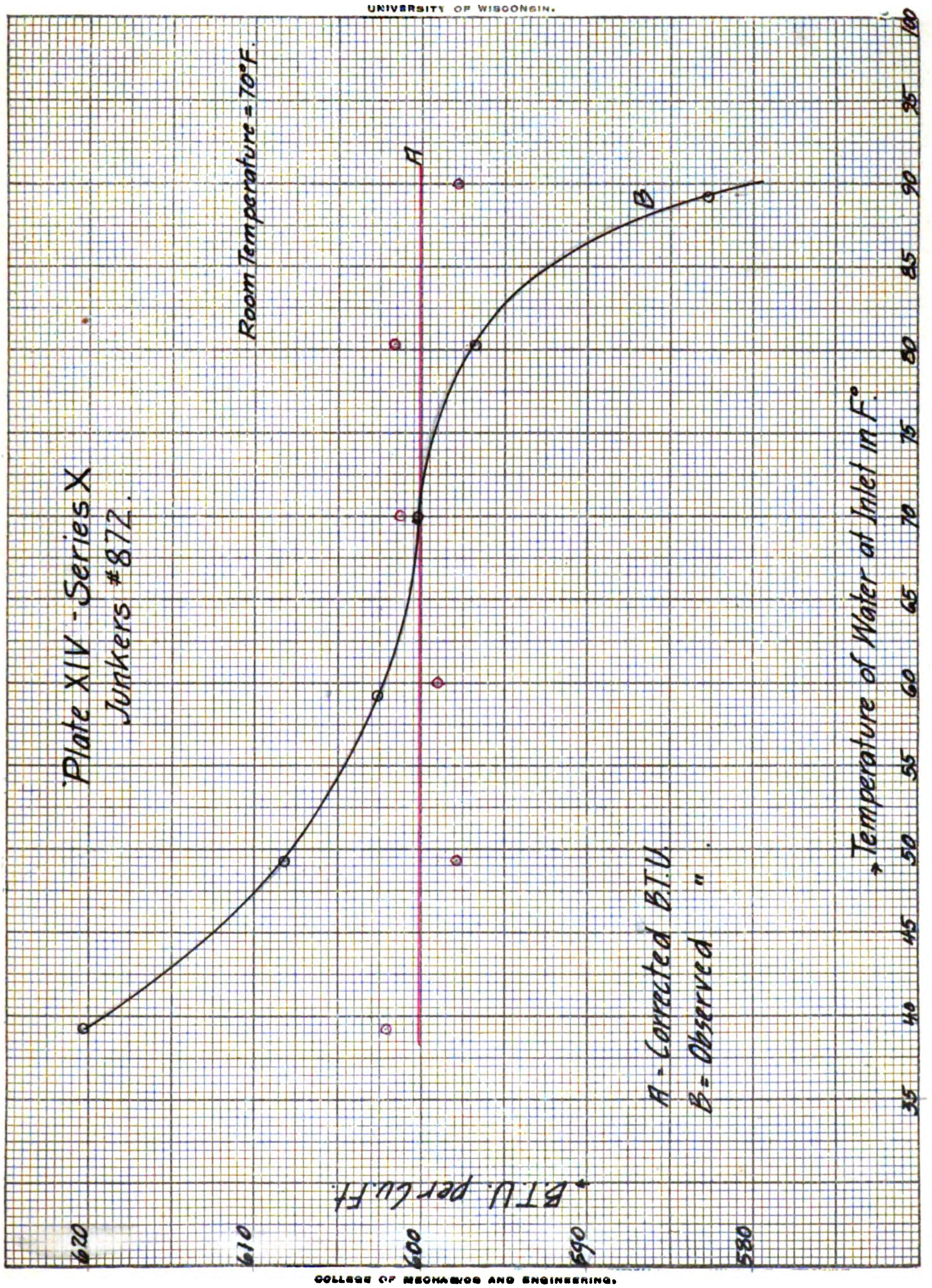
UNIVERSITY OF WISCONSIN.



COLLEGE OF MECHANICS AND ENGINEERING.


UNIVERSITY OF WISCONSIN.
Plate XIV - Series X
Junkers #872.
Room Temperature = 70°F.
A
B
A - Corrected B.T.U.
B = Observed "
Temperature of Water at Inlet in F°.
B.T.U. per Cu. Ft.
35
40
45
50
55
60
65
70
75
80
85
90
95
100
620
610
600
590
580
COLLEGE OF MECHANICS AND ENGINEERING.

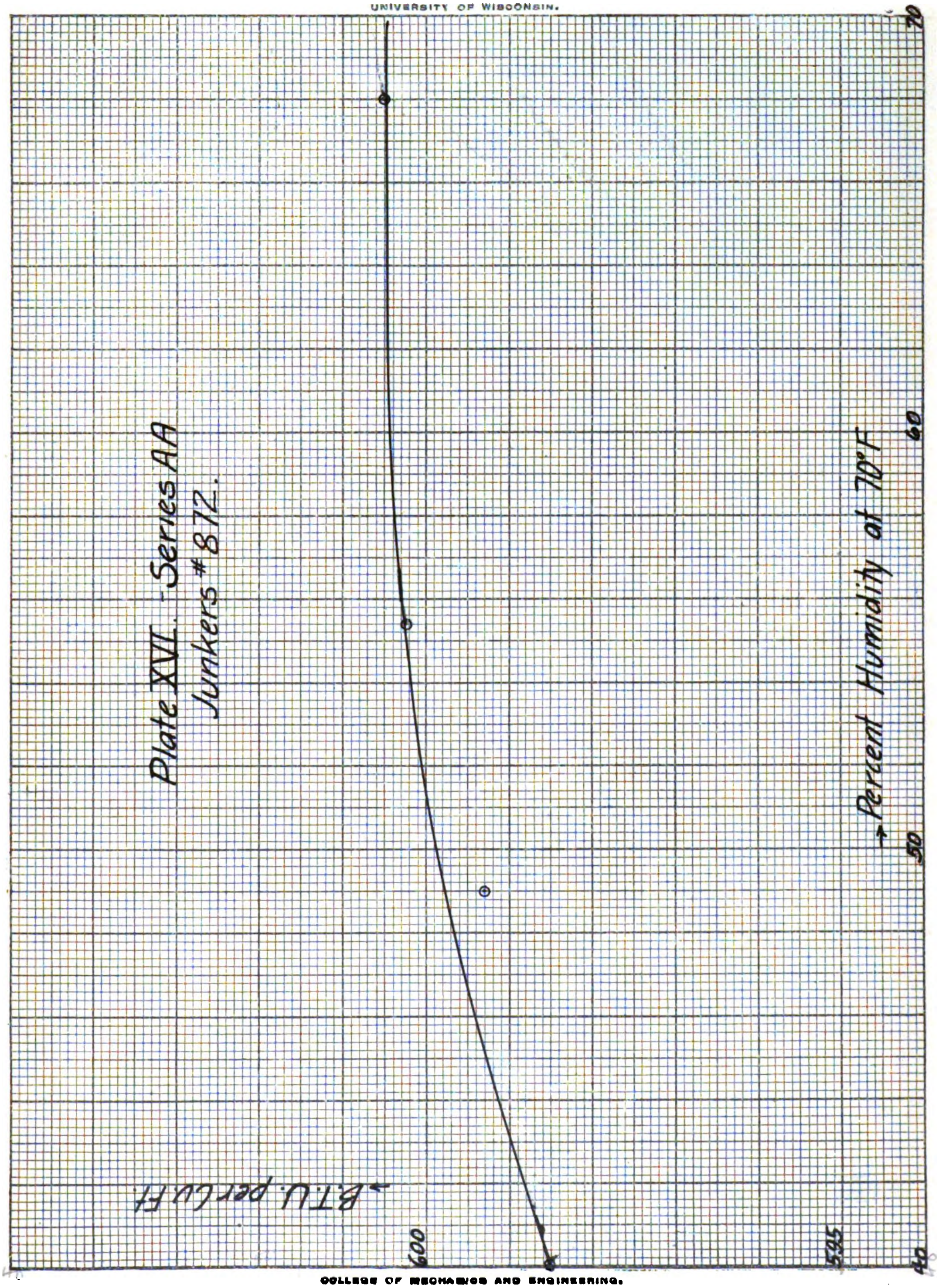


Plate XVI. - Series AA
Junkers # 872.
Percent Humidity at 70°F
B.T.U. per Cu. Ft.
70
60
50
40
600
595

UNIVERSITY OF WISCONSIN.

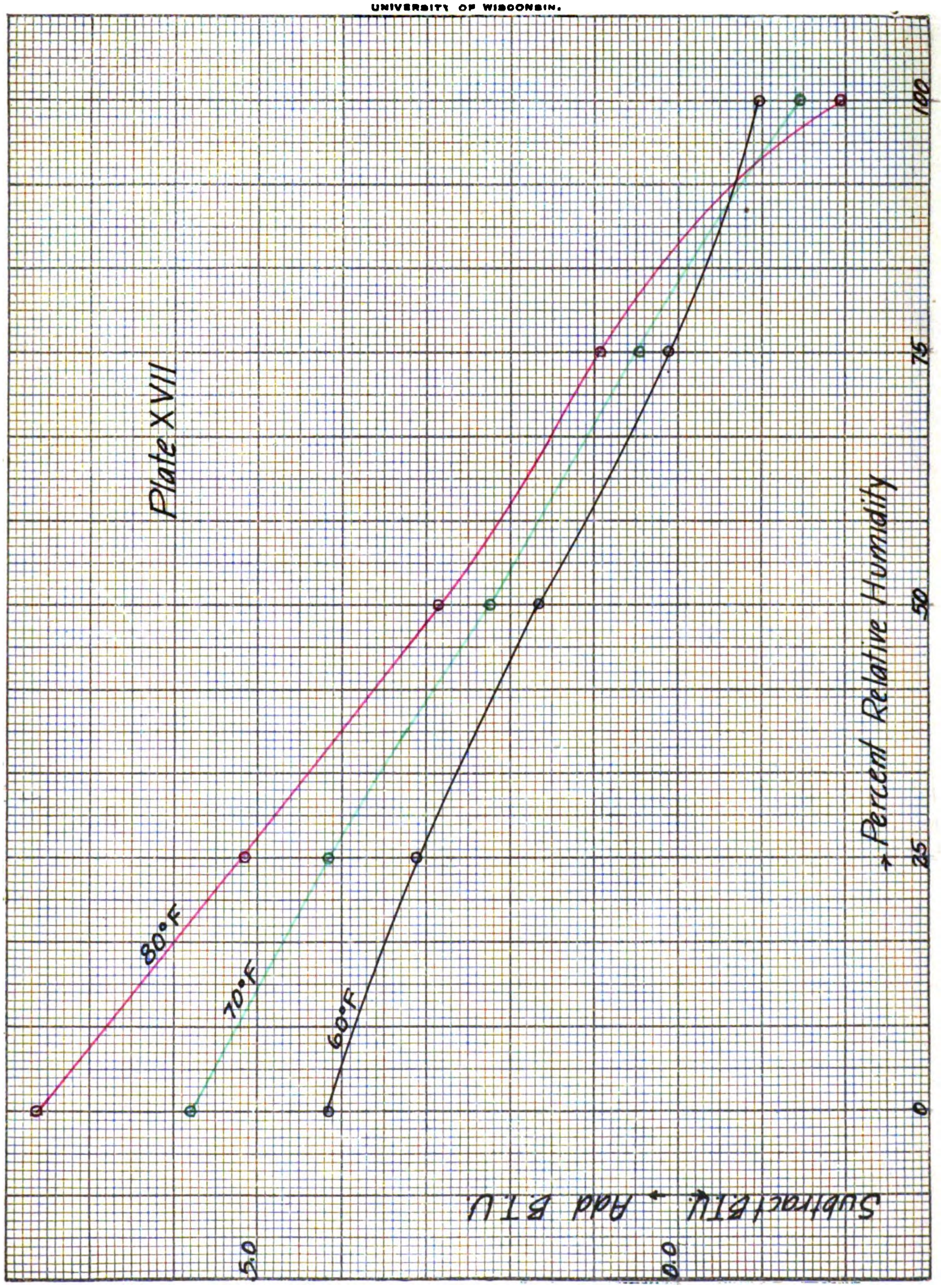


Plate XVII

COLLEGE OF MECHANICS AND ENGINEERING.

Baro

Temp

Corr

Humi

Room

Exha

Gas

Gas

Wate

Inle

Outl

Diff

B. T

Bar		2
Tem		7
Cor		.
Hum		5
Roo		7
Exh		8
Gas		3
Gas		.
Wat		6
Inl		2
Out		3
Dif	4	1
B.		6

Barometer
Temperature
Correction F
Humidity
Room Tempera
Exhaust Temp
Gas Rate Cu.
Gas Consumed
Water Heated
Inlet Temper
Outlet Tempe
Difference
B. T. U.

Baromete

Temperat

Correcti

Temperat

Temperat

Rate of

Gas Cons

Water He

Inlet Te

Outlet T

Differen

B. T. U.

06

	6
Baromete	29.09
Temperat	73.4
Correcti	0.9348
Temperat	75.0
Temperat	74.5
Gas Rate	7.07
Gas Cons	0.2
Water he	6.8695
Inlet Te	70.395
Outlet T	86.065
Differen	15.670
B. T. U.	575.7

Barometer

Temperatur

Correction

Humidity

Room Tempe

Exhaust Te

Gas Rate C

Gas Consum

Water heat

Inlet Remp

Outlet Tem

Rise in Te

BT.U.

06

6

29.09

73.4

0.9348

75.0

74.5

7.07

0.2

6.8695

70.395

86.065

15.670

575.7

	06
	6
Barometer	29.09
Temperature	73.4
Correction	0.9348
Humidity	75.0
Room Tempera	74.5
Exhaust Tem	7.07
Gas Rate Cu	0.2
Gas Consume	6.8695
Water heate	70.395
Inlet Temp.	86.065
Outlet Temp	15.670
Rise in Tem	575.7
B. T. U.	

	06 6
Barometer	29.09
Temp. Gas "	73.4
Correction	0.9348
Humidity	75.0
Room Temp.	74.5
Exhaust Tem	7.07
Gas Rate Cu	0.2
Gas Consume	6.8695
Water Heate	70.395
Inlet Temp.	86.065
Outlet Temp	15.670
Rise in Tem	575.7
B. T. U.	

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Dist

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Ver

Est

Est

ter

TABLE 7. SERIES P.

JUNKERS #872.

	1	2	3	4	5	6
Barometer	29.09	29.09	29.09	29.09	29.09	29.09
Temperature of Gas	73.04	73.13	73.22	73.31	73.4	73.4
Correction Factor	0.9359	0.9355	0.9353	0.9350	0.9348	0.9348
Room Temperature	74.65	74.9	74 9	74.9	74.95	75.0
Exhaust Temperature.	74.0	74.5	74.5	74.5	74.5	74.5
Gas Rate Cu. ft./Hr.	7.07	7.07	7.07	7.07	7.07	7.07
Gas Consumed Cu. ft.	0.2	0.2	0.2	0.2	0.2	0.2
Water Heated - Lbs.	6.8717	6.8563	6.8519	6.8563	6.8585	6.8695
Inlet Temp.	69.888	69.98	70.064	70.182	70.306	70.395
Outlet Temp.	85.572	85.66	85.758	85.873	85.991	86.065
Difference F°	15.684	15.68	15.694	15.691	15.685	15.670
B. T. U.	575.8	574.6	574.8	575.3	575.2	575.7

TABLE 7. SERIES P.

SIMMANCE-ABADY

	1	2	3	4	5	6
Barometer	29.09	29.09	29.09	29.09	29.09	29.09
Temperature Gas	73.04	73.13	73.22	73.31	73.40	73.40
Correction Factor	0.9359	0.9355	0.o353	0.935	0.9348	0.9348
Room Temperature	74.65	74.9	74.9	74.90	74.95	75.0
Exhaust Temperature	75.0	75.0	74.9	74.9	74.9	74.9
Gas Rate Cu. ft./Hr.	4.08	4.08	4.08	4.08	4.08	4.08
Gas Consumed Cu. ft.	0.2	0.2	0.2	0.2	0.2	0.2
Water Heated - Lbs.	7.2046	8.9926	7.2046	7.2068	7.1782	7.1826
Inlet Temperature	69.948	70.022	70.118	70.283	70.380	70.454
Outlet Temperature	86.455	86.331	86.331	86.651	86.836	86.777
Difference F°	16.509	16.309	16.213	16.368	16.456	16.323
B. T. U.	635.3	627.1	624.4	630.8	631.8	627.1

TABLE 7. SERIES P.

SIMMANCE-ABADY

	1	2	3	4	5	6
Barometer	29.09	29.09	29.09	29.09	29.09	29.09
Temperature Gas	73.04	73.13	73.22	73.31	73.40	73.40
Correction Factor	0.9359	0.9355	0.o353	0.935	0.9348	0.9348
Room Temperature	74.65	74.9	74.9	74.90	74.95	75.0
Exhaust Temperature	75.0	75.0	74.9	74.9	74.9	74.9
Gas Rate Cu. ft./Hr.	4.08	4.08	4.08	4.08	4.08	4.08
Gas Consumed Cu. ft.	0.2	0.2	0.2	0.2	0.2	0.2
Water Heated - Lbs.	7.2046	8.9926	7.2046	7.2068	7.1782	7.1826
Inlet Temperature	69.948	70.022	70.118	70.283	70.380	70.454
Outlet Temperature	86.455	86.331	86.331	86.651	86.836	86.777
Difference F°	16.509	16.309	16.213	16.368	16.456	16.323
B. T. U.	635.3	627.1	624.4	630.8	631.8	627.1

TABLE 9. SERIES K.

JUNKERS #872.

	1	2	3	4	5
Room Temperature	74.65	74.65	74.9	75.2	75.3
Exhaust Temperature	79.5	79.5	79.5	79.5	79.5
Time of Test in Min.	3	3	3	3	3
Water heated in grams	4140.	4139.	4142.	4133.	4137.
Temp. Inlet "F"	72.679	72.622	72.692	72.71	72.68
Temp. Outlet "F"	87.646	87.657	87.671	87.671	87.642
Rise in Temp. "C"	8.315	8.3305	8.322	8.312	8.312
Volts on heating Coil	86.643	86.70	86.6977	86.645	86.555
Amperes " " "	9.295	9.2956	9.295	9.290	9.285
Small Calories put in	34602.5	34627.52	34624.4	34593.3	34530.19
" " observed	34424.1	34479.9	34469.7	34453.49	34386.7
Per cent efficiency	99.48	99.57	99.55	99.30	99.58

Room Temperature	.
Exhaust Temperatu	.
Water Heated -Gr	32.
Inlet Temp. "F"	.248
Outlet Temp. "C"	.889
Rise in Temp. "C"	589
Time of Tests in	0.
Volts	.844
Amperes	786
Small Calories pu	553.407
Small " obser	448.398
Efficiency	.2

TABLE 11. SERIES T.

SARGENT

	1	2	3	4
Room Temperature	71.	71.	71.	71.
Exhaust Temp.	77.	77.	77.	77.
Water Heated - Grams	3223.	3187.	3168.	3182.
Inlet Temp. "F"	64.954	64.493	64. 375	64.248
Outlet Temp. "F"	80.468	80.098	80.0	79.889
Rise in Temp. "C"	8.619	8.6694	8.6805	8.689
Time of Test - Seconds	180.	180.	180.	180.
Volts	95.332	95.027	94.919	94.844
Amperes	6.82	6.8.	6.79	6.786
Small Calories put in	27934.956	27763.925	27691.824	27653.40
Small Calories observed	27779.057	27629.378	27499.824	27448.39
Efficiency %	99.5	99.5	99.3	99.2

Barometer

Gas Temperature

Correction Factor

Room Temperature

Exhaust Temperature

Gas Rate Cu. ft./Hr.

Gas Consumed Cu. ft.

Water Heated - Lbs.

Inlet Temp.

Outlet Temp.

Difference F°

B. T. U.

TABLE 13. SERIES X.

JUNKERS #872.

	1-4	5-8	9-12	13-16	17-20	21-24
Barometer	28.79	28.77	28.73	28.70	28.66	28.63
Temperature Gas	69.4	68.35	67.8	67.7	68.1	68.15
Correction Factor	0.9354	0.9374	0.9374	0.9366	0.9344	0.9328
Humidity %	62.	62.	62.	75.	88.	100.
Room Temperature	69.	68.5	68.5	69.5	70.8	70.4
Exhaust Temperature	45.6	54.2	63.2	72.4	81.5	88.6
Gas Rate Cu. ft./Hr.	6.78	6.77	7.05	6.9	6.91	6.92
Gas Consumed Cu. ft.	0.2	0.2	0.2	0.2	0.2	0.2
Water Heated - Lbs.	7.499	7.428	7.251	7.306	7.295	7.255
Inlet Temp. "C"	3.894	9.585	15.352	21.314	26.765	31.819
Outlet Temp. "C"	12.496	18.098	23.953	29.844	35.259	40.132
Difference F°	15.482	15.279	15.518	15.385	15.289	14.972
B. T. U.	620.2	608.2	601.2	600.2	596.8	582.1

TABLE 14. SERIES AA

JUNKERS #872

	1	2	3	4
Barometer	29.06	29.04	29.04	29.00
Temperature Gas	68.4	68.2	68.0	67.82
Correction Factor	0.9466	0.9469	0.9466	0.9465
Humidity	40.	49.	56.	68.
Room Temperature	70.	69.5	69.	69.
Exhaust Temperature	72.5	73.	72.5	72.5
Gas Rate Cu. ft./Hr.	6.79	6.80	6.80	6.80
Gas Consumed Cu. ft.	0.2	0.2	0.2	0.2
Water Heated - Lbs.	8.113	8.102	8.107	8.11
Inlet Temp.	70.481	70.715	70.456	70.624
Outlet Temp.	84.450	84.734	84.480	84.634
Difference	13.969	14.019	14.024	14.010
B.T.U.	598.5	599.5	600.3	600.5

Thesis of Otto L. Kowalke.

Approved :

C. F. Burgess

Victor Lenher

Jno G D Mack

June 14 . . . 1909.

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